U. S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

MANUAL OF TIDE OBSERVATIONS

SPECIAL PUBLICATION No. 196
REVISED (1941) EDITION

U. S. DEPARTMENT OF COMMERCE
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FOREWORD

This is one of a series of manuals published by the United States Coast and Geodetic Survey for the purpose of giving the general requirements of the Bureau in carrying on its various activities. This volume contains instruction for the observations of tides and the usual reductions necessary for the determination of datum planes and the nonharmonic quantities published in the Tide Tables. Directions for taking temperature and density observations are also included for the convenience of tide observers who take such observations in connection with their regular duties at the tide stations.

Corresponding instructions for tidal current observations are given separately in Special Publication No. 215, Manual of Current Observations. The harmonic computations required for the prediction of tides and currents are described in Special Publication No. 98, Manual of Harmonic Analysis and Prediction of Tides.

The present work supersedes a previous edition of the manual published in 1935 and contains a revised description of the standard automatic tide gage to include recent improvements in this instrument. This manual was prepared by Paul Schureman, Principal Mathematician, under the direct supervision of Capt. Paul C. Whitney, Chief of Division of Tides and Currents.

CONTENTS

ILLUSTRATIONS

MANUAL OF TIDE OBSERVATIONS

PURPOSES OF TIDE OBERVATIONS

1. The tidal work of the Coast and Geodetic Survey is carried on for the purpose of serving the needs of the mariner, the engineer, the scientist, and the public generally. The work had its origin in the necessity for reducing to a common level or datum plane, soundings taken at different stages of the tide, and this still constitutes one of the important purposes. Among other outstanding purposes are (a) the determination of tidal datum planes for general engineering work, (*b*) the derivation of data for the prediction of tides, (*c*) the securing of information pertaining to the mean and extreme rise and fall of the tide which may be necessary in the construction of piers, bridges, and other structures for which the tidal condition is an important factor, (*d*) the securing of data for the study of crustal movements in the earth. A continuous series of tide observations in any region also provides data for the reduction of shorter series of observations in nearby areas and furnishes information often required in connection with legal cases involving maritime interests.

2. Tide stations may be classified as primary and secondary. Primary stations are those at which observations are to be continued for a number of years for the purpose of deriving basic tidal data for the locality. A secondary station is one which is operated over a very limited period of time to obtain tidal information for a particular purpose and the length of series will depend upon that purpose.

TIDE GAGES

3. A tide gage is an instrument for measuring the height of the tide. Tide gages may be divided into two groups—nonregistering gages which require the presence of an observer to take and record the height of the tide, and self-registering or automatic gages which automatically record the rise and fall of the tide while unattended.

4. The first group includes the tide staff and some types of float and pressure gages. The second group includes a variety of types, some of which record the rise and fall of the tide in the form of a graph, others by printed figures, and others photographically. The two principal kinds of automatic tide gages used by the Coast and Geodetic Survey record by means of graphs. One of these, known as the "standard automatic tide gage," is designed for use at primary tide stations or where observations are to be continued for a considerable period of time. The other, known as the "portable automatic tide gage," was designed for use at tide stations which are to be continued for only a short period and where ease of installation is a desired factor.

TIDE STAFF

5. The simplest kind of tide gage is a plain staff, which may consist of a board 1 to 2 inches thick and 4 to 6 inches wide, graduated in feet and tenths. The length should be sufficient to extend from the lowest to the highest tide which may reasonably be expected in the locality where the staff is to be used. Such a staff is secured in a vertical position to a pile or other suitable support, with the graduations increasing upward. When nailed in place or otherwise secured so as not to be easily removable, it is called a *fixed staff*.

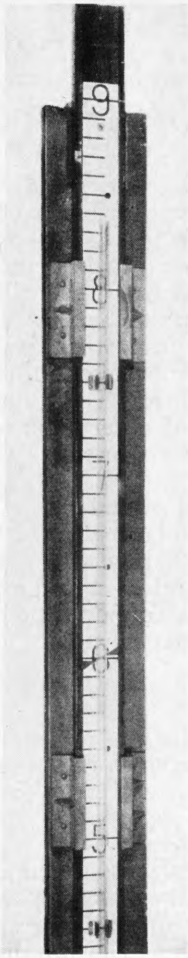

FIGURE 1.—Portable tide staff and support.

6. Vitrified scale.—To overcome difficulties resulting from the defacement of the graduations on a wooden tide staff, which may become illegible after a comparatively short time, the office has adopted a set of scales graduated in feet and tenths, which are made by baking a vitrified coating on wrought-iron strips. The strips are in 3-foot sections about 2½ inches wide, the sections being so graduated that when placed end to end form a single continuous scale. The scales may be secured to a wooden staff or suitable piece of timber, brass screws and lead washers being provided for the purpose.

7. Glass tube.—For use in rough water a glass tube about ½ inch in diameter is secured to the face of the tide staff by spring clips or other devices. The lower end of the tube is partially closed by means of a notched cork to dampen down the motion of the water inside.

8. Portable staff.—After a fixed tide staff has been in the water for a considerable period of time, particularly in harbors where there is much refuse or fuel oil, the graduations may become more or less illegible. To avoid this, there are used at many of the tide stations a portable tide staff (fig. 1) which may be easily removed from the water and stored under shelter when not in actual use. The tide staff may be constructed in hinged sections for convenience in storing. In order that such a staff shall always have its zero at the same elevation when placed in the water for use, a tide staff support permanently secured in place is necessary.

9. The tide staff support, with length corresponding approximately with that of the portable staff, may be constructed of 2-inch plank somewhat wider than the tide staff and covered with copper sheathing as a protection against teredos and other marine borers. A metal plate at the top of the support forms a shoulder on which a metal stop secured to the back of the tide staff rests when the staff is in position for use, thus assuring a fixed

elevation for the staff zero. At intervals along the support, metal guides are arranged in pairs to hold the staff in a vertical position.

10. Multiple staff.—Along shore where shoal water extends some distance offshore and the range of tide is too large to be measured by a single staff, a succession of staffs may be used. The different staffs should be so graduated and installed that the graduations will be continuous from one staff to the next with the readings on all of the staffs referred to the same zero.

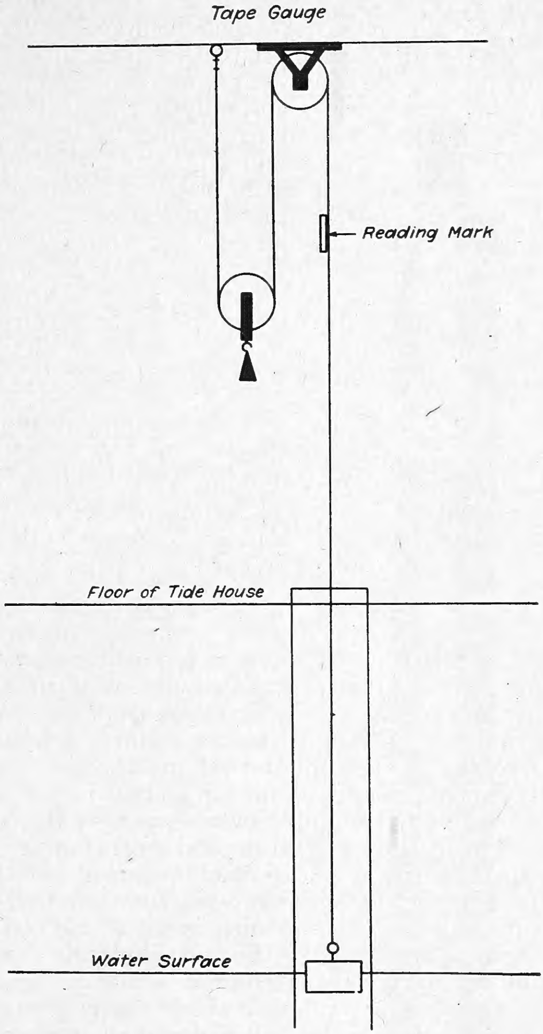

FIGURE 2.—Tape gage.

TAPE GAGE

11. The tape gage (fig. 2) is designed as a substitute for the tide staff in exposed localities where the water is too rough for staff readings. It is operated by a float in a vertical box or pipe, known as a *float well*, which serves to dampen out the larger wind waves. (See pars. 65–72 for a discussion of float wells.) Connected with the float is a tape which passes over a pulley in the ceiling of the tide house and is kept taut by means of a counterpoise. In general, it is best to have the counterpoise supported by a movable pulley with the end of the tape attached to the ceiling of the tide house in order to increase the limits of operation of the apparatus. With a very small range of tide or a very high ceiling, however, the counterpoise may be attached directly to the free end of the tape.

12. There are several kinds of tape gages. In some, an index or pointer attached to the tape moves over a fixed scale. In others, as

represented in figure 2, there is a fixed reading mark on a board and the height of the tide is read on the tape graduations as they pass the fixed mark. In the latter case, the tape graduations, expressed in feet and hundredths, should increase towards the float so that the readings will increase with a rising tide. The tape itself may be either stainless steel or a bronze alloy—the advantages of the former being flexibility and legibility, and of the latter durability. Some of the advantages of both may be secured by using the bronze alloy for the lower section of the tape which is normally in the float well and the stainless steel for the upper section from which the readings must be taken.

13. The float for the tape gage must be cylindrical in shape in order that small changes in the plane of flotation will not affect the cross-section area in this plane. The top and bottom, however, may be tapered to permit easy passage over any roughness which may be accidentally contacted inside the float well. Either the $8\frac{1}{2}$-inch float of the standard automatic gage or the $3\frac{1}{4}$-inch float of the portable gage may be used for the purpose, but the larger float is to be preferred as its plane of flotation is more stable and less sensitive to change from frictional resistance in the operation of the gage.

14. When a tape gage is used, a distinction must be made between a visible scale zero and the true datum of the gage to which the observed heights are referred. The tape gage datum may be defined as the level of the water surface at the time the gage reading is zero. This will obviously be a number of feet lower than any visible scale zero inside the tide house. For the installation of a tape gage and the determination of its datum see page 29.

PIPE GAGE

15. The pipe gage is a type of float gage which has been used on offshore shoals in a depth of 30 feet of water. This gage consists of a white-pine rod staff, cross section 1 by 1 inch, with rounded edges, graduated on each of the four sides in feet and two-tenths with the zero (0) at the top, and set in a hollow cylindrical white-pine float $1\frac{1}{2}$ inches outside diameter and $\frac{7}{8}$-inch inside diameter. The float should be thoroughly covered with shellac and liquid paraffin. The length of the rod will depend upon the range of tide in the locality where it is to be used and the length of the float should be about four-tenths that of the rod. The float well consists of a 2-inch iron pipe, the bottom of which is set in a 1,000-pound concrete block to serve as an anchor. The pipe should be long enough to reach above the ordinary waves at high tide and a $\frac{1}{2}$-inch hole should be drilled in the pipe several feet above the concrete anchor. A cap with a square hole through which the staff passes, is screwed on top of the pipe after the float staff has been placed inside. Just below the cap a 2-inch flange for the attachment of guy wires is screwed on the pipe and four small sheaves, one for each guy wire, secured to this flange by wire loops. The top of the float pipe is secured in a vertical position by four guy wires of No. 6 wire with leads making an angle of 60° or more with the vertical. The end of each guy wire is anchored to

concrete blocks, giving a total weight of about 2,000 pounds to each anchor. For convenience in handling each concrete block may be cast with wire rope loops projecting. After the anchors have been set the guy wires are led through the sheaves at the top of the float pipe and drawn taut, a fence-wire stretcher being convenient for this purpose.

PRESSURE GAGE

16. The pressure gage operates by measuring the variation in pressure at the bottom of a body of water due to the rise and fall of the tide. Although not as satisfactory as the types of gages usually employed for tide observations close to shore, pressure gages have been used with some success for observations taken on shoals at some distance from land where it has been impracticable to install the usual type of gage.

FATHOMETER

17. The fathometer is primarily an instrument for measuring the depth of water but, since this depth varies with the rise and fall of the tide, the instrument also has been used with some success for observing tides from a ship at anchor offshore. The measurements depend upon the interval of time required for a sound wave to travel from the ship to the bottom of the ocean and for its echo to return. A full description of the instrument will be found in the Coast and Geodetic Survey Hydrographic Manual. When using the fathometer as a tide gage, the ship should be anchored where the ocean bottom is near level as possible, so that there will be no material change in depth due to the swinging of the vessel. The anchorage should be buoyed and the observations repeated on different days to detect irregularities due to causes other than the tide. The instrument might also be operated with the transceiver anchored to the bottom of the ocean, in which case the sound wave first travels upward and is then reflected from the water surface back to the transceiver. By this method the tide record would not be affected by irregularities in the ocean bottom at the ship's anchorage.

STANDARD AUTOMATIC TIDE GAGE

18. The present standard automatic tide gage used by the Coast and Geodetic Survey is a development of the Stierle gage adopted by this Survey many years ago. A float operates in a vertical box or pipe to which the slow moving tide has free access while the more rapid moving waves resulting from winds are largely damped out by the relatively small size of the inlet to the box. The rising and falling of the float operates a worm screw on the gage which moves a pencil to and fro across a wide strip of paper which is moved forward by clockwork. The combined motion of pencil and paper gives a continuous graph showing the rise and fall of the tide.

19. Names of parts.—For convenience of reference there are given below the names applied to different parts of the standard automatic tide gage. The numbers correspond to those given in figures 4 to 9.

1. Time clock.
2. Motor clock.
3. Clock case.
4. Supply roller.
5. Tension guide springs (2).
6. Pencil screw.
7. Pencil arm return springs (2).
8. Drum shaft ball bearings (2).
9. Drum shaft bearing caps (2).
10. Counterpoise drum or reel.
11. Float drum or reel.
12. Capstan lock nut, counterpoise drum.
13. Capstan lock nut float drum.
14. Main roller.
15. Bracing rod.
16. Tension weight drum or reel.
17. Receiving roller.
18. Receiving roller release buttons (2).
19. Winged nuts securing clock unit (4).
20. Datum pencil rod.
21. Datum pencil clamp.
22. Datum pencil holder clamping nut.
23. Datum pencil holder.
24. Datum pencil.
25. Datum pencil clamping screw.
26. Hour-tripping rod.
27. Clamping screws, tripping rod assembly (2).
28. Tripping hook stop.
29. Striker weight.
30. Striker weight clamping screw.
31. Striker weight spring.
32. Striker lifter binding screw.
33. Striker lifter.
34. Carrier arm.
35. Carrier wheel.
36. Hour tripping hook.
37. Recording pencil.
38. Recording pencil holder.
39. Recording pencil clamping screw.
40. Pencil holder adjusting screw.
41. Pencil arm.
42. Pencil weight.
43. Pencil arm bearing screw.
44. Pivot screws for pencil holder (2).
45. Capstan bearing pin for pencil screw.
46. Lock screw.
47. Lock nut.

20. Clock unit.—The clock unit consists of two clocks mounted on a frame. The one on the right (1, fig. 4) is known as the *time clock* and the one on the left (2) without hands as the *motor clock.* For convenience, the corresponding sides of the tide gage may be called the *time side* and the *motor side.* The time clock operates the device which makes the hour marks on the record, while the motor clock serves to regulate the forward movement of the paper. By having a separate clock to move the paper, the time clock is relieved of unnecessary work and may therefore be more accurately regulated for recording the correct time. Moreover, the use of two clocks aids in securing a continuous record, because if either one of the clocks stops for a short period, it is sometimes possible to interpret the record during this period through the functioning of the remaining clock.

21. The clock unit is secured by four winged nuts (19, fig. 8) on the back of the clock case and is interchangable with other units when replacements are necessary. In the older types of the instrument, the two clocks were mounted independently in the clock case, the time clock on the left and the motor clock on the right.

22. Each clock has an 8-day movement and may be regulated and corrected as similar clocks in ordinary use. To avoid injury to the hour-marking device of the time clock, however, the minute hand must not be turned backward when between 10 minutes before and 5 minutes after the hour "12." The hour hand may be turned in either direction, and if it is necessary to turn the clock backward within the limits noted above, it may be accomplished by turning the hour hand back a full hour and the minute hand forward to the correct time.

Figure 3.—Standard automatic tide gage (with cover).

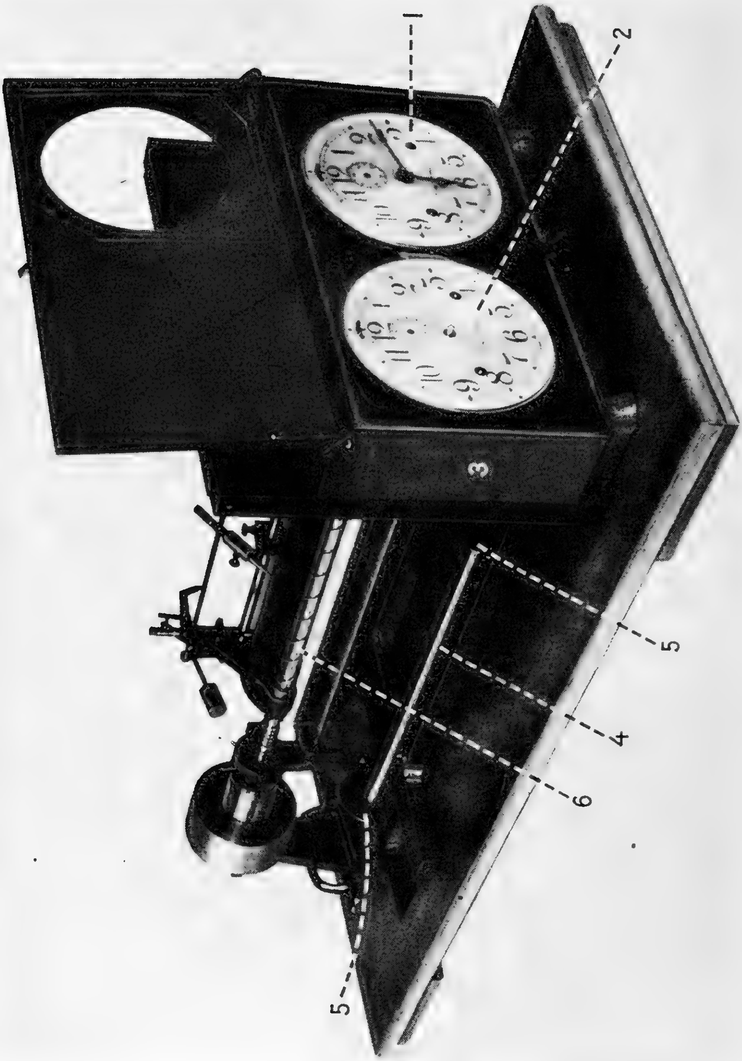

FIGURE 4.—Standard automatic tide gage (front view).

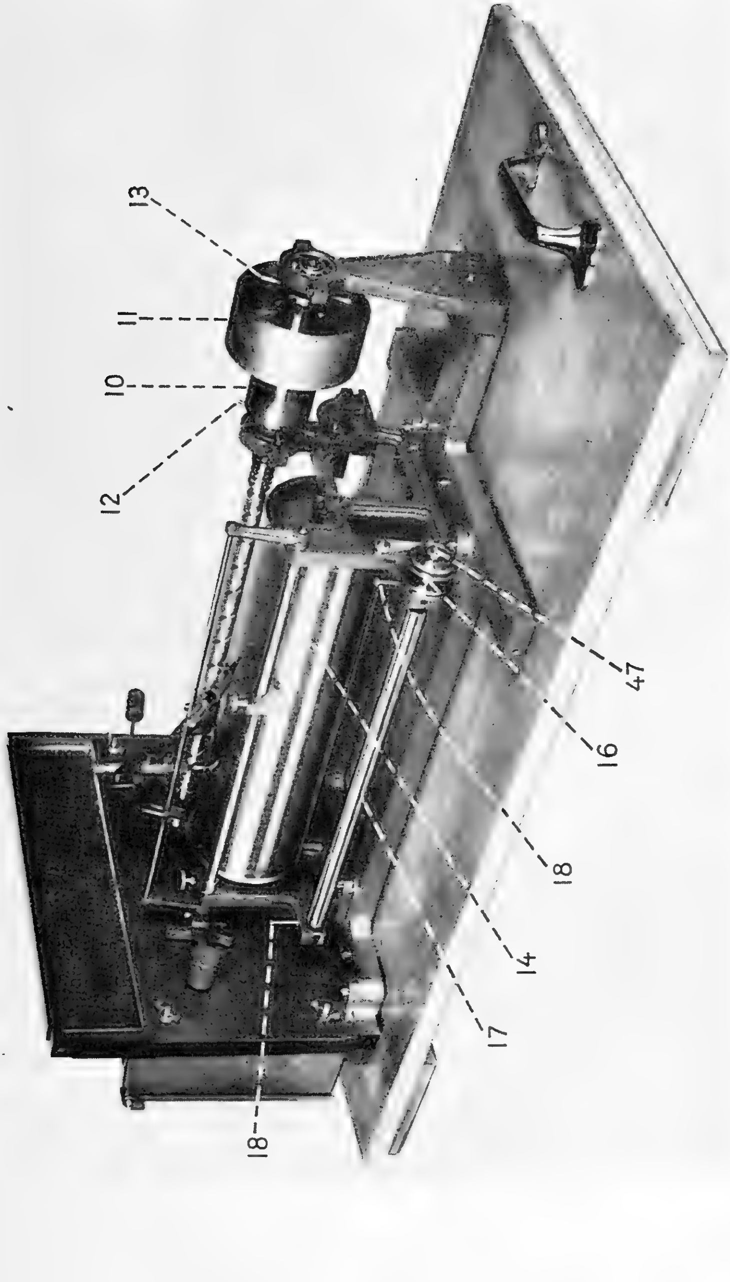

FIGURE 5.—Standard automatic tide gage (side and back).

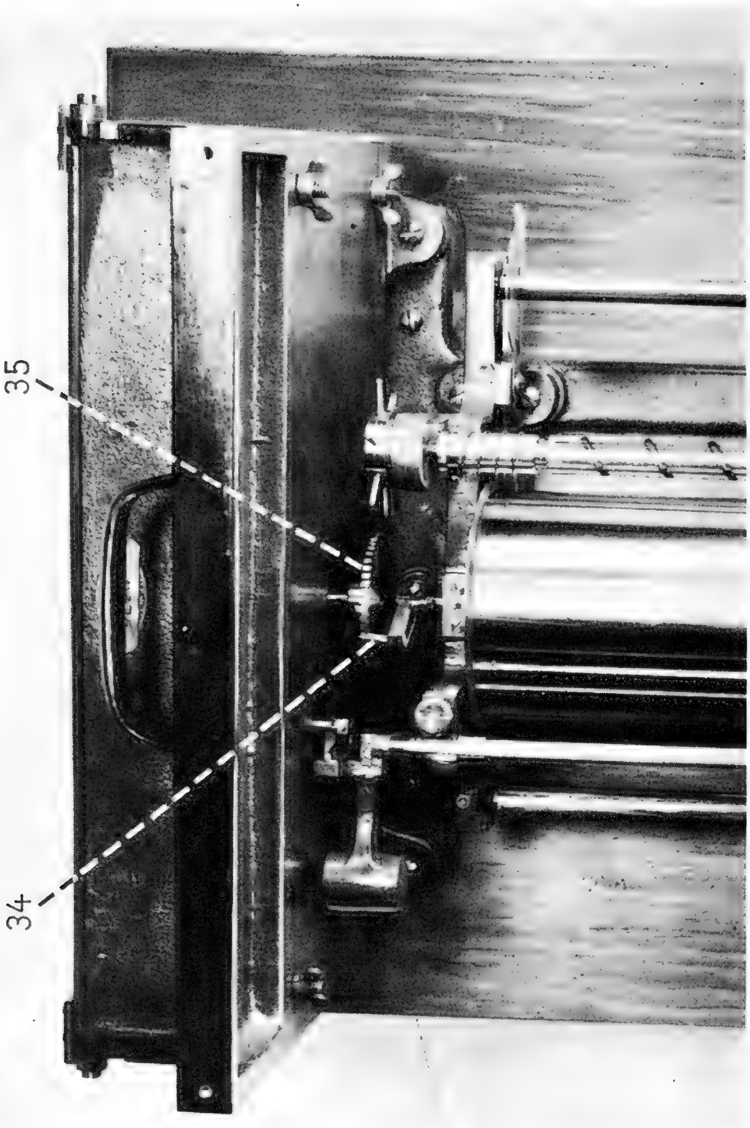

FIGURE 6.—Standard automatic tide gage (clock connection).

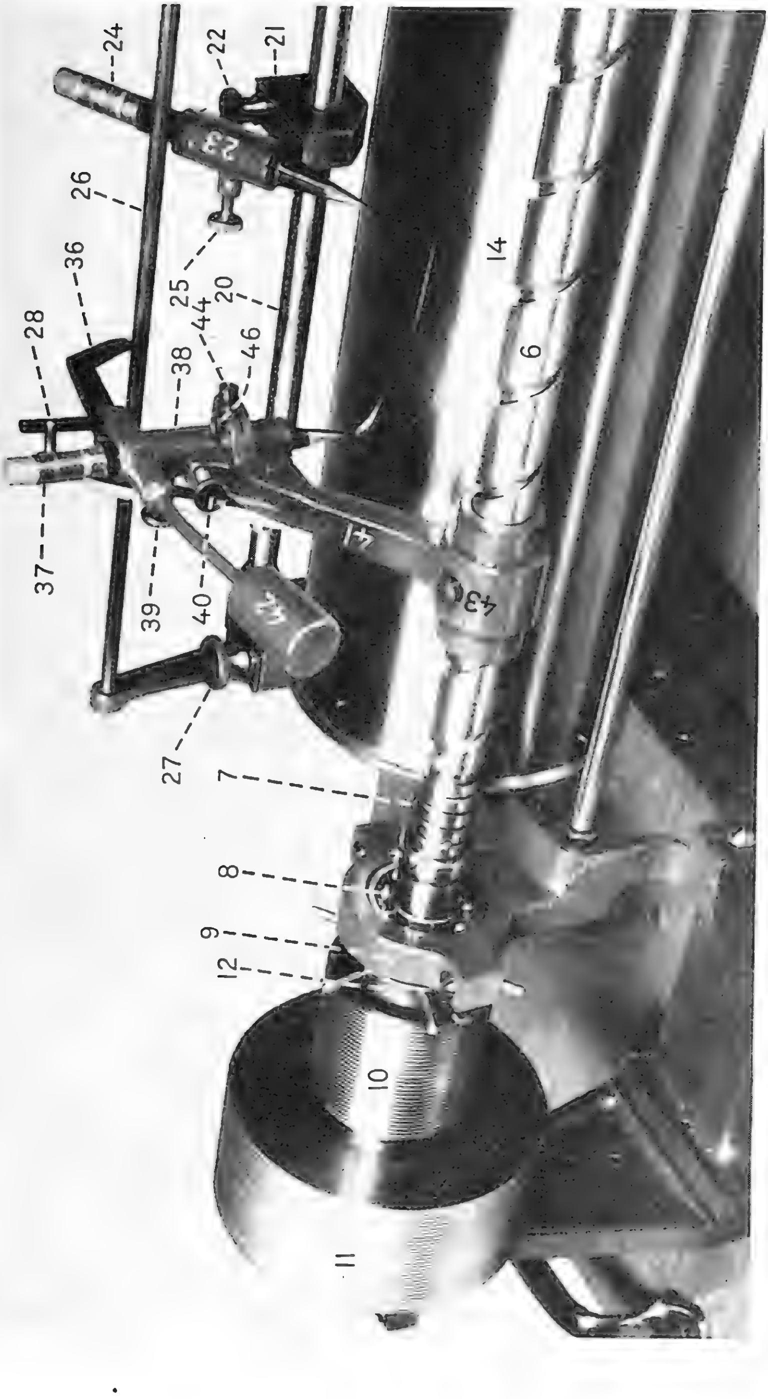

FIGURE 7.—Standard automatic tide gage (recording pencils).

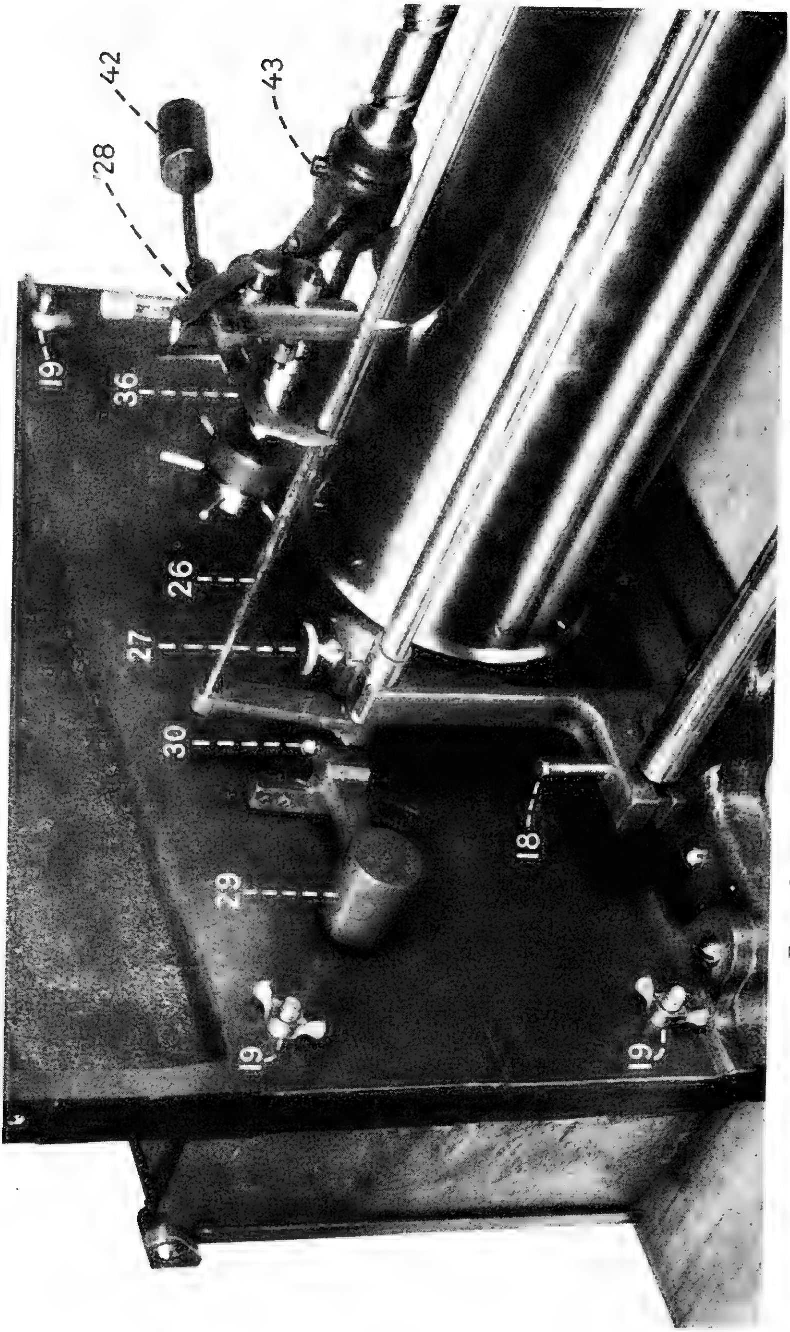

FIGURE 8.—Standard automatic tide gage (right forward end).

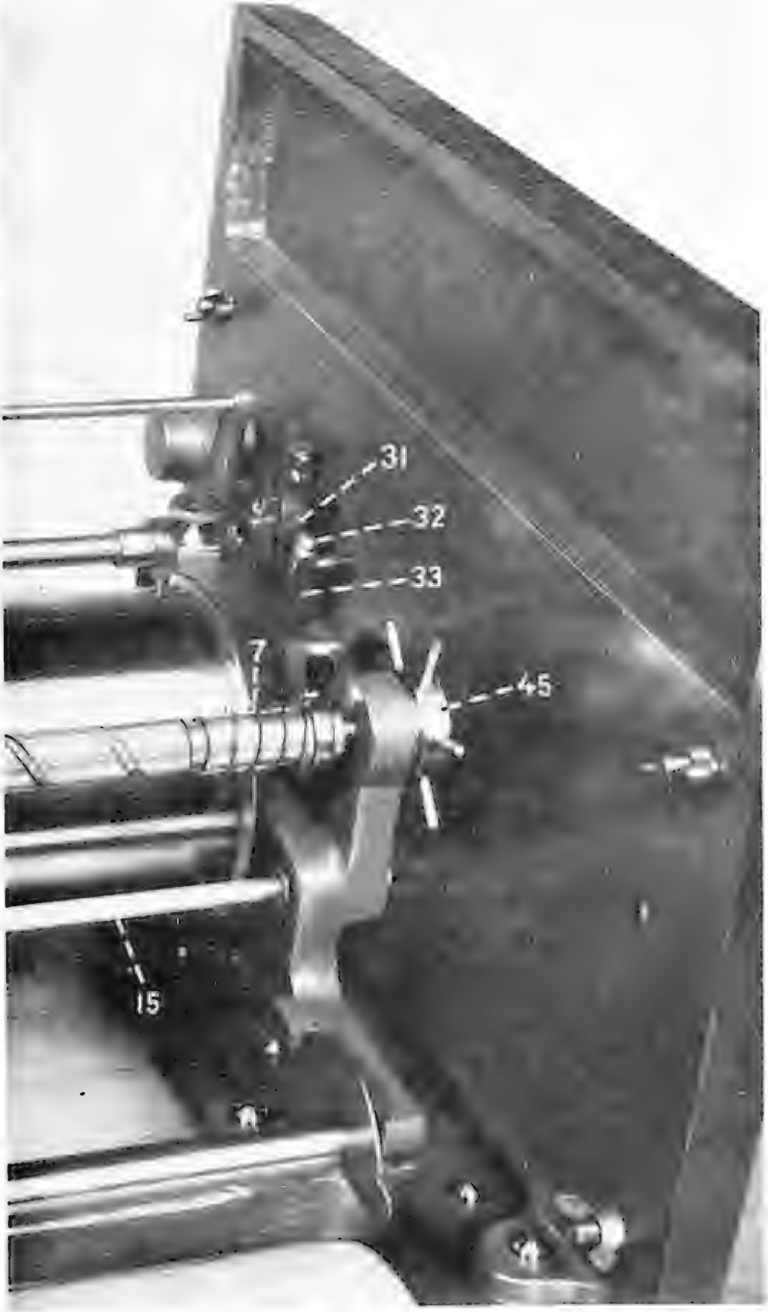

FIGURE 9.—Standard automatic tide gage (left forward end).

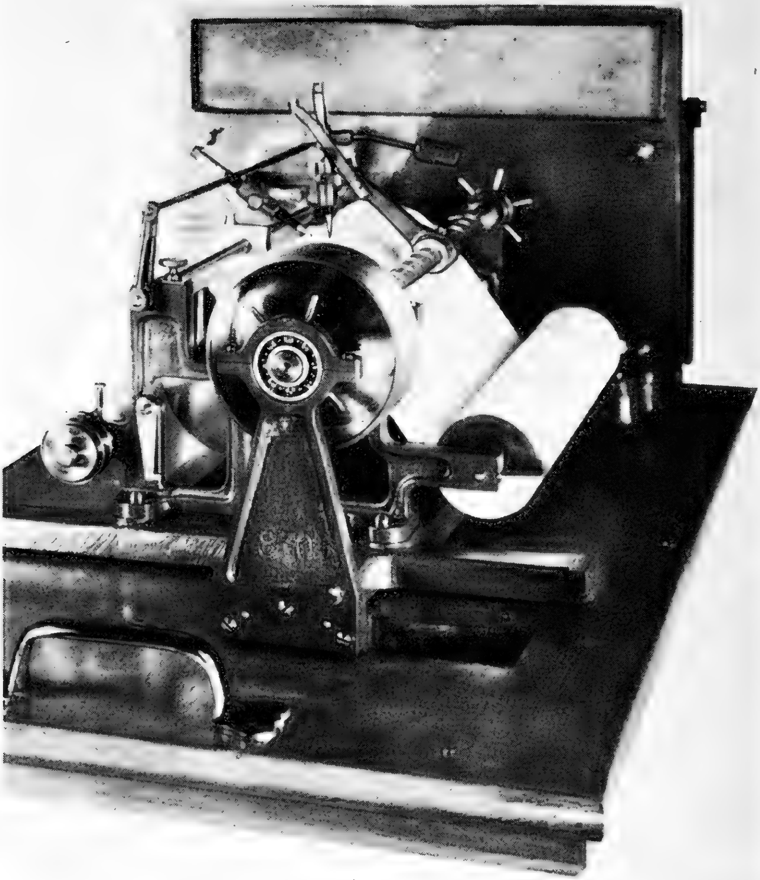

FIGURE 10.—Standard automatic tide gage (paper installation).

23. If the time clock runs consistently fast day after day, the regulating lever should be moved slightly toward the letter "S"; and if consistently slow, the lever should be moved toward the letter "F," care being taken not to move the lever so far as to introduce an error in the opposite direction. A movement of the regulating lever of 1 division usually changes the rate about 3 minutes per day. If the loss or gain in any 1 day is less than 3 minutes, it is, in general, inadvisable to move the regulator unless there has been a similar loss or gain on a number of consecutive days. No refined regulation is necessary for the motor clock. Normally this runs at a rate which moves the paper forward 1 inch an hour, but any small variation from this rate is unimportant.

24. A spindle operated by the motor clock extends through the back of the clock case and has secured to its extremity a toothed carrier wheel (35, fig. 6), also known as the clutch wheel, which actuates the main roller of the gage when engagement is made through a hinged carrier or clutch arm (34) attached to the roller. Projecting

from the time clock through the back of the clock case is a spindle carrying a short arm (33, fig. 9) called the striker lifter. This is actuated by a cam in the clock and operates the hour-marking device.

25. **Rollers.**—There are three rollers on the gage, which are designated as the *supply roller*, the *main roller*, and the *receiving roller*. The *supply roller* (4, fig. 4) is a solid rod on which the blank roll of paper is placed. When installing a new roll of paper, this rod may be readily removed from the gage and passed through the hole in the center of the blank roll. When on the gage it is held in place by guide springs (5) at each end. These springs also press against the ends of the roll of paper to keep it from unwinding too fast and thus hold the paper taut as it is fed over the main roller. The pressure exerted by these springs may be regulated by slightly bending them.

26. The **main roller** (14, fig. 5) is a hollow cylinder 13¼ inches long and 12 inches in circumference. Near each end of the cylinder sharp steel pins are set at 1-inch intervals to keep the record paper from slipping. Attached to the axis of the cylinder at one end there is a hinged carrier arm (34, fig. 6) which engages the carrier wheel geared to the motor clock. Through this connection the main roller is rotated at the approximate rate of one turn in 12 hours, thus feeding the paper forward at the rate of 1 inch per hour.

27. The **receiving roller** (17, fig. 5), which is designed to receive the completed record, consists of a solid core with one side flattened and an outer shell in which a slit runs the entire length. With the slit opposite the flattened side of the core, the end of the paper is inserted and then secured in place by a slight turn of the shell. The roller is held in place in its bearings by two pins which may be released by pressure on buttons (18) near the ends of the roller. At one end of the roller there is a small drum (16) known as the *tension weight drum*, upon which is wound a cord attached to a weight which serves to wind up the record paper on the receiving roller. The drum is arranged so that it can be turned independently of the receiving roller when winding up the weight. In some of the instruments this is accomplished by a pawl and ratchet, while in other instruments the loosening of a lock nut enables the drum to be moved aside, thus disengaging it from the roller itself.

28. **Record paper.**—The paper for the standard automatic tide gage is furnished in rolls about 13 inches wide and containing approximately 66 feet in length, which is sufficient for 1 month of record. The paper is plain without any ruling. After the tide curve has been traced upon the tide roll the record is called a *marigram*.

29. **Pencil screw.**—The pencil screw (6, fig. 4) is a rod about ⅝ inch in diameter with a square screw thread with a 1-inch pitch, except that for a very large range of tide a screw with a ½-inch pitch is used. The pencil screw is rotated through the action of the float as the tide rises and falls, and in turn actuates the pencil arm causing a pencil to trace the record. The threads at each end of the pencil screw are turned down to prevent the pencil arm from jamming on reaching the extreme limits of the rod, and springs (7, figs. 7 and 9) are provided at each end to return the arm to the threaded portion of the screw as soon as the tide reverses. In the latest type of instrument the pencil screw may be removed from the gage for cleaning without disturbing the wiring to float or counterpoise. At one end

it is connected with the drum shaft by a slotted joint and at the other end is held in place by a capstan bearing pin (45, fig. 9). By backing off this bearing pin the pencil screw is easily released so that it may be lifted out.

30. Recording pencil.—The recording pencil (37, fig. 7) traces the tide curve. This pencil is secured in its holder (38) by a clamping screw (39). The gage is provided with a special automatic pencil but any ordinary pencil with a medium soft lead can be used for the purpose. The holder is secured to the pencil arm (41) by two pivot screws (44) which permit a small lateral movement for striking the hour marks. One pivot screw is clamped by a lock screw (46). In the bearing of the pencil arm there is a pin screw (43) which fits into the thread of the pencil screw, and as the latter is rotated through the action of the tide, the pencil arm is moved toward the clock unit or away from the same according to whether the tide is rising or falling.

31. Datum pencil.—The datum pencil (24, fig. 7), which draws the datum line from which the record is scaled, is similar to the recording pencil. Its holder is secured to the rod (20) by a clamp (21). This clamp consists of a split block held together by two screws. One of the screws is covered by the spring attached to the holder and must be tightened before the spring is placed in position. The other screw is secured by the clamping nut (22) after the holder has been ad justed to the position desired.

32. Hour-marking device.—The hour-marking device is actuated by the time clock. A cam attached to the main shaft of the clock turns with the minute hand and operates a lever which is connected with a small arm (33, fig. 9) projecting from the back of the clock case. This arm presses against a spring (31) attached to the striker weight (29, fig. 8). The latter is secured by a binding screw (30) to a rod that actuates the tripping rod (26). Beginning 30 minutes before the time for striking the hour, the cam in the clock gradually swings the small arm upward, raising the striker weight and moving the tripping rod in toward the recording pencil. On the exact hour the cam suddenly releases this arm, thus causing the weight to fall and the rod to move suddenly outward. The latter strikes the end of the hour-tripping hook (36) attached to the pencil holder, causing the pencil to make a short hour mark parallel to the edge of the paper. Through the action of the pencil weight (42) the pencil is then immediately returned to its original position.

33. Float and counterpoise drums.—The *float drum* (11, fig. 5), which operates the pencil screw, is threaded to accommodate the wire to which the float is attached. The *counterpoise drum* (10) is similarly threaded for the wire to the counterpoise. A small hole or a clamp near one edge of each drum affords a means for attaching the wire. The drums now in use are either 1⅛ or 1¾ inches wide. As the threads are cut 16 turns to the inch, the narrower drums will accommodate 18 turns of wire and the larger ones 28 turns. To provide suitable recording scales for different tidal ranges, interchangeable float drums of different sizes may be used. Those now available have circumferences of 6, 9, 12, 16, and 24 inches. The counterpoise drum is 6 inches in circumference for all scales. The wiring on the two drums is so arranged that one winds as the other unwinds.

34. In the old type of gage, the counterpoise drum was mounted directly on one end of the pencil screw and the float drum was then clamped to the counterpoise drum. In the newer instruments with removable pencil screw, the two drums are mounted independently on a short rod, known as the *drum shaft*, which turns in ball bearings at each end and is connected with the pencil screw by a slotted joint. Around the middle of the drum shaft is a flange which separates the two drums and contains a pin projecting from both sides which is designed to engage one of a series of holes in the end of each drum. The drums are held against this flange by capstan lock nuts (12, 13, fig. 5), which may be loosened independently to release either drum so that it may be turned when installing a new wire. In the normal operation of the gage these lock nuts are not to be disturbed since any change in the position of the float drum on its shaft will affect the adjustment of the gage.

35. Wire.—The float and counterpoise drums are designed for use with No. 23 American gage wire which is 0.024 inch in diameter, and wire of this size must be used to preserve the correct scale in the operation of the gage. Formerly a single-strand phosphor-bronze or nickel-chromium wire was used for suspending the float and counterpoise weight, but there is now available a seven-strand stainless steel wire containing 18 percent chromium and 8 percent nickel, which is more satisfactory for the purpose.

36. Float.—The standard float now used for the automatic tide gage has a cylindrical section 8½ inches in diameter and 2 inches high with tapering top and bottom sections. Its weight is 4½ pounds. Assuming the weight of sea water, fresh water, and kerosene to be, respectively, 64 pounds, 62.4 pounds, and 55 pounds per cubic foot, the corresponding buoyancy per inch of immersion of the cylindrical section of the float is 2.10 pounds, 2.05 pounds, and 1.81 pounds, respectively. In the normal operation of the gage with a strain of from 12 to 16 ounces on the float wire, the float will be approximately one-half submerged. As a free float the immersion will be about one-half inch deeper.

37. Counterpoise.—The counterpoise acts upon the counterpoise drum to take up the slack in the float wire as the tide rises. Although it may be attached directly to the end of the counterpoise wire, it is preferable to have it act through a movable pulley with the end of the wire fastened to the ceiling of the tide house as this arrangement increases the operating limits of the gage when the height of the ceiling is otherwise insufficient to provide for the full range of tide. The weight of the counterpoise together with the operating scale of the gage determines the amount of tension on the float wire. As a tension of 12 to 16 ounces has been found to be generally the most satisfactory, the weight should be selected accordingly. The weights recommended for use with different size float drums will be found in paragraph 89.

38. Tension weight.—This weight, acting upon the drum at one end of the receiving roller, serves to wind up the paper on which the record is traced, and, by keeping a tension on the paper, also assists the motor clock in turning the main cylinder. A silk fish line is generally used to connect the weight with the drum. This is called the *tension cord*. The weight may be either attached directly to the end of the cord or supported from a movable pulley with the end of the cord

attached to the ceiling of the tide house. The latter method is to be preferred as it increases the period during which the gage will operate with a single winding up of the weight A weight of 1 pound is recommended regardless of whether it is used with or without a movable pulley. When suspended from a movable pulley, the extra weight of the latter offsets the reduced strain on the cord resulting from this arrangement.

39. Scale of gage.—The height scale of the gage depends upon the circumference of the float pulley and the pitch of the pencil screw. The different scale combinations are shown in the table below:

Scale combinations

Float drum circumference	Pencil screw pitch	Scale of gage	Range limit		
			Curve	Extreme	
Inches	*Inch*		*Feet*	*Feet*	*Feet*
6	1	1:6	6	9	14
9	1	1:9	9	13	21
12	1	1:12	12	18	28
16	1	1:16	16	24	37
24	1	1:24	24	36	56
16	½	1:32	32	24	37
24	½	1:48	48	36	56

In the above table the range limit of the curve shows the maximum range that can be recorded by a continuous curve with the scale indicated. Beyond this limit the pencil arm becomes disengaged from the threads of the pencil screw and further rise and fall is registered by a series of jogs near the margin of the paper. The extreme range which can be recorded by these jogs depends upon the size of the float drum. In the columns for the extreme range limit two values are given for each scale. The first value is the limit when float and counterpoise drums have a width of 1⅛ inches, and the second value when the width is 1¾ inches.

PORTABLE AUTOMATIC TIDE GAGE

40. The portable automatic tide gage was designed by this Bureau primarily for use in obtaining short series of observations for the reduction of soundings in hydrographic surveys. The aim was to provide a gage more portable and more easily installed than the standard gage. Besides being smaller, it differs in a number of ways from the larger gage. It is equipped with a single roller and a single clock movement, the latter being concealed inside the roller. A counterpoise spring is substituted for counterpoise weight. It is provided with a smaller float which operated in a convenient size iron pipe which serves also as a support for the gage. An iron cover protects the gage from the weather or molestation and eliminates the necessity for any specially built shelter. The record is drawn on sheets of cross-section paper which may be conveniently removed from the gage when desired. Although some degree of the precision of the standard gage has been sacrificed to gain the conveniences of the smaller gage, it is sufficiently accurate for the purpose for which

it was designed, but its use for a long series of observations is not recommended.

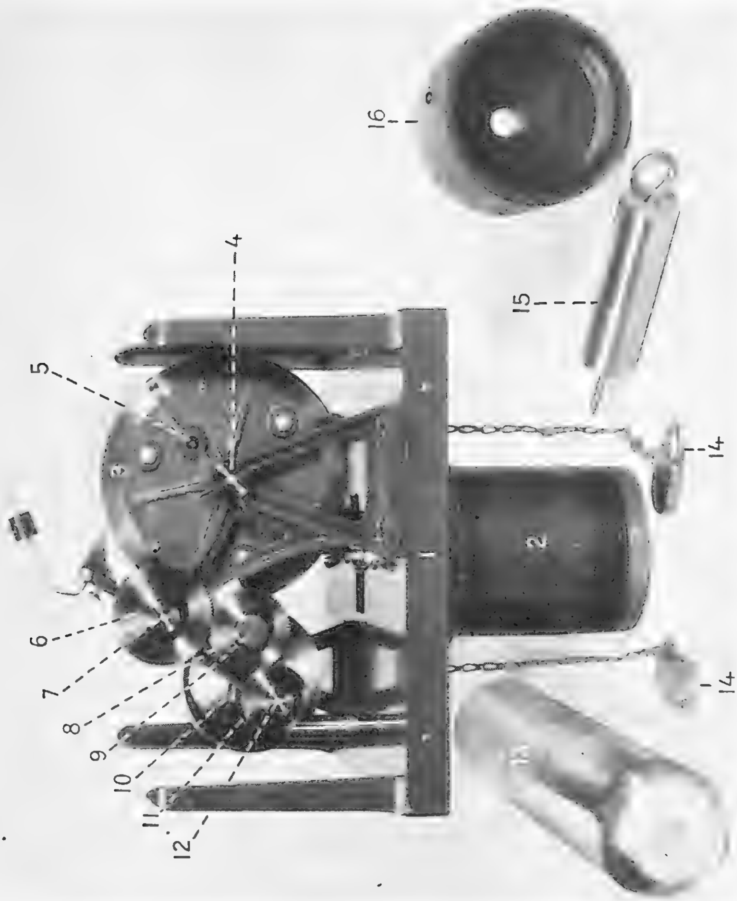

FIGURE 11.—Portable automatic tide gage (front).

41. Names of parts.—Three views of the portable automatic tide gage with parts numbered are shown in figures 11 to 13. Following are the names corresponding to the numbered parts:

Figure 11	Figure 12	Figure 13
1. Base.	17. Float drum.	26. Fair leader clamping screw.
2. Float pipe section.	18. Float drum axle screw.	27. Float pipe anchor hooks.
3. Record cylinder.	19. Float drum axle.	28. Counterpoise spring pawl.
4. Clamping nut for record cylinder.	20. Oil container.	29. Counterpoise spring ratchet.
5. Keyhole for winding clock.	21. Stylus screw.	30. Counterpoise spring axle.
6. Stylus screw gear.	22. Stylus resting bar.	31. Float drum cover plate.
7. Stylus screw gear nut.	23. Stylus arm return springs.	32. Screw covering oil hole.
8. Idle gear.	24. Paper holding clip.	33. Stylus arm.
9. Idle gear screw.	25. Height adjustment screw.	34. Time adjustment screw.
10. Idle gear lever nut.		35. Stylus holder.
11. Float drum gear.		36. Stylus.
12. Float drum gear nut.		37. Stylus weight.
13. Float.		38. Stylus arm bearing.
14. Cover locks.		
15. Cleaning tool.		
16. Intake coupling.		

42. Record cylinder.—The record cylinder (3, fig. 11) on which the paper for the record is wound is 7 inches in length and 19.2 inches in circumference. The cylinder is geared to a clock movement carried within itself which causes it to rotate on an axle through its center. The axle is clamped in its supports by a capstan nut (4, fig. 11) and the cylinder should be so placed that this nut is on the same side of the instrument as the train of gear wheels. In this position the cylinder rotates in such a direction that the top moves towards the stylus screw. The cylinder is provided with a clip (24, fig. 12) for holding the record paper in place.

43. Clock movement.—An 8-day clock movement is mounted inside the record cylinder, its function being to rotate the cylinder at a uniform rate, which is once in 48 hours. The circumference of the cylinder moves forward 0.4 inch per hour, the time scale of the record. Keyholes for winding and regulating are in the end of the cylinder containing the clamping nut.

44. Stylus screw.—The stylus screw (21, fig. 12) is actuated by a train of gears connecting with the float drum and operates the arm that carries the recording stylus, moving this arm backward and forward as the tide rises and falls. The screw is made of phosphor bronze and has a square screw thread with a pitch of 0.4 inch. The screw thread terminates in circular grooves at each end to prevent the stylus arm from jamming when the limit of its movement is reached, and springs (23, fig. 12) are provided to force the arm back again on the thread when the tide reverses. A gear wheel (6, fig. 11) is clamped to one end of the screw by a milled-head nut (7, fig. 11) and may be released when it is desired to reset the stylus.

45. Stylus arm.—The stylus arm (33, fig. 13), which carries the recording stylus, has in its bearing a pin that fits into the thread of the stylus screw and when the latter is turned with the rising and falling of the tide the arm moves backward and forward along the screw. The stylus arm carried a small weight (37, fig. 13) to overcome the tendency to be thrown back on a rising tide. A stylus holder (35, fig. 13) is pivoted to the arm. Two slow-motion screws act upon this holder—one (34, fig. 13) is designed for a refined time setting of the stylus, and the other (25, fig. 12) is designed to set the stylus to an exact height reading.

46. Recording stylus.—The recording stylus (36, fig. 13) consists of a pointed blade, designed to trace the record on a specially prepared wax-coated paper. The stylus is so shaped that it will ride smoothly over the clip that holds the paper in place. In some of the older types of the gage, ordinary pencils and special chronograph pens have been used, neither of which proved entirely satisfactory. Special difficulties arose in the use of ink in the chronograph pen because of the excessive dampness to which the record paper is often exposed at the tide stations.

47. Float drum.—The float drum (17, fig. 12) is 12 inches in circumference and about 1 inch wide with the face threaded to accommodate 30 turns of the float wire. The drum, together with its oil-tight cover (31, fig. 13), forms a housing for the counterpoise spring. The drum is rigidly fastened by means of a screw (18, fig. 12) to that part of its axle (19, fig. 12) connected with the gear wheel.

The subsidiary axle (30, fig. 13) on the opposite side of the drum is attached to one end of the counterpoise spring and does not turn with the drum.

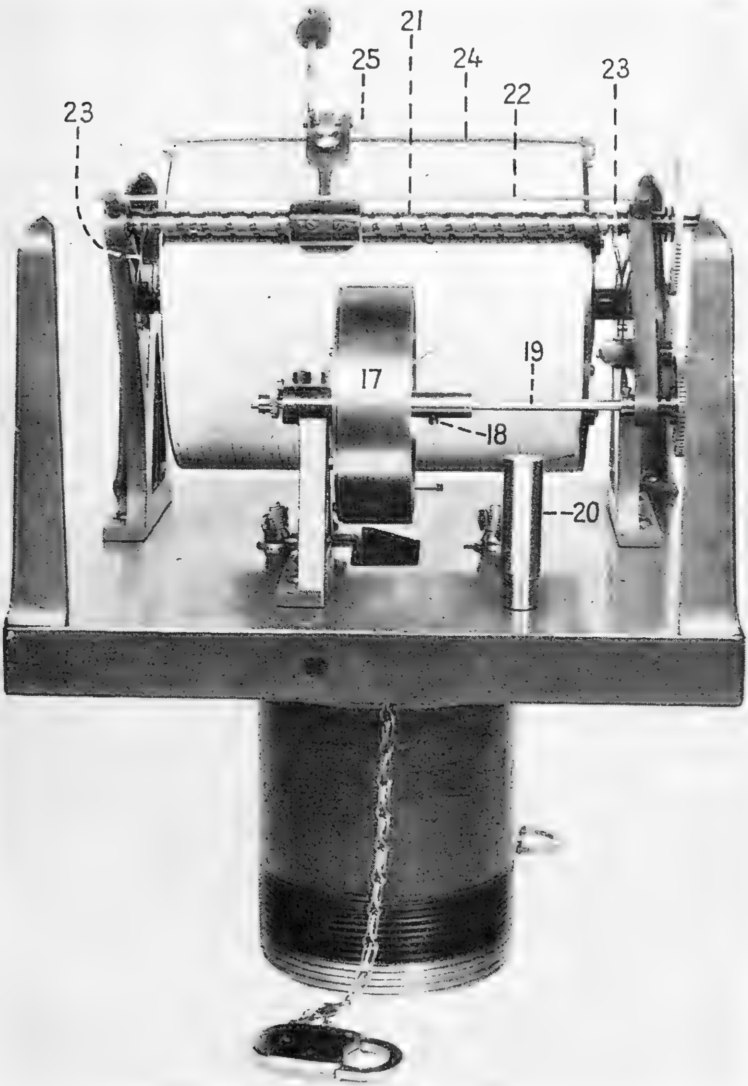

FIGURE 12.—Portable automatic tide gage (left side).

48. Counterpoise spring.—The counterpoise spring enclosed in the float wire drum operates against the weight of the float and takes up the slack in the float wire as the tide rises. One end of the spring is fastened to the inside of the drum and the other end is attached to the subsidiary axle (30, fig. 13). The latter is held fixed by a ratchet

and pawl (29, 28, fig. 13) during the ordinary operation of the gage but may be turned by a clock key when it is desired to increase the tension of the spring. The spring is about 18 feet long and is com-

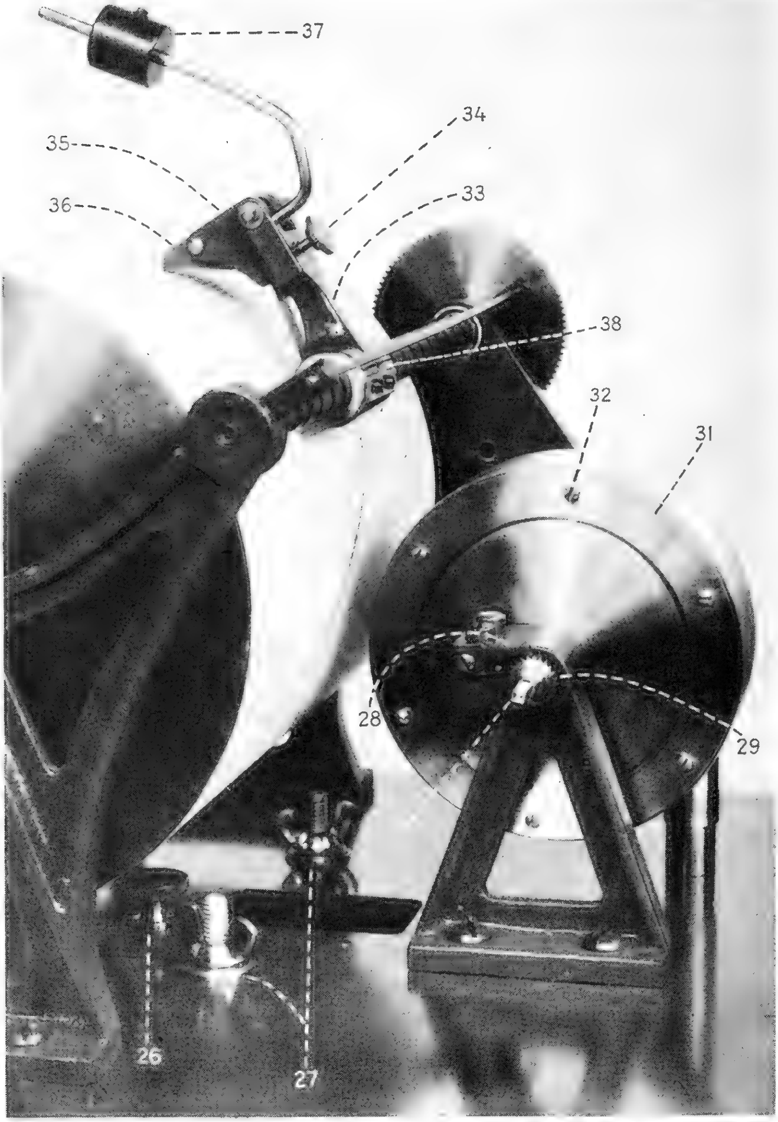

FIGURE 13.—Portable automatic tide gage (detail of stylus and float drum).

pletely wound by about 40 turns of the drum. The spring operates in a bath of watch oil which is introduced through one of the screw holes in the cover plate (32, fig. 13).

49. To replace a broken spring proceed as follows: Loosen screw (18, fig. 12) which holds the shaft connecting the float-wire drum with

its driving gear, then take out the six screws holding the cover plate (31, fig. 13) and remove it from the face of the drum. Slide the drum away from the standard toward the gear train and remove the screw which fastens the inner end of the spring to the fixed shaft. (This screw is slotted in its shank instead of in its head.) Take out the screw holding the other end of the spring in the drum and remove broken spring. Now, put in the screw, which is slotted in its shank, through the round hole in the inner end of the new spring and fasten this end of the spring in place to the fixed shaft, wind the spring so that it will fit into its recess in the drum and attach its outer end in the drum case by means of the screw provided for that purpose, and reassemble. About a teaspoonful of fine watch oil should be put inside the case through the charging hole, which is closed by means of one of the six small screws (32, fig. 13) holding the cover plate in place.

50. Fair leader.—This is a pulley mounted on a brass arm attached to the bottom of the base of the instrument and extending down inside the short section of float pipe. It is secured in place by a clamping screw (26, fig. 13). Its purpose is to guide the float wire from its drum to the center of the float well.

51. Gears.—The float wire drum actuates the stylus screw through a train of three gears (11, 8, 6, fig. 11). The two gears (11, 6) are interchangeable with other gears furnished with the instrument to obtain different scale ratios. The middle gear (8) is an idler used for all scale ratios and provision is made for an adjustment of its position to properly mesh with the other gears in use. Each gear has the number of teeth stamped in the metal and the combinations to be used are shown in the accompanying table:

Scale	Maximum range of tide	Number of teeth	
		Gear attached to float-drum axle	Gear attached to stylus screw
1:11¼	6	96	36
1:16⅞	9½	96	54
1:22½	12½	96	72
1:30	17	72	72
1:45	25	64	96

52. Scale of gage.—By changing the combination of gears as indicated in the table above, five different height scales may be obtained ranging from 1:11¼ to 1:45. The maximum range of tide which can be recorded as a continuous curve with the different scales is also indicated in the table. However, if an unexpected extreme high or low water does carry the stylus to one end of the stylus screw beyond the limit, evidence is usually left which will enable an experienced tabulator to determine the approximate height reached by the tide. The absolute limit of range which can be recorded by the present gage, operating under usual conditions, is fixed by the length of wire

which can be wound upon the float-wire drum, which is approximately 30 feet.

53. Record paper.—The record paper for the portable automatic tide gage (fig. 22) consists of sheets with special cross-section ruling. These sheets are 7 inches wide and 19.7 inches long allowing for a ½-inch overlap, the ruled portion being 19.2 inches long to correspond to the circumference of the record cylinder. The coordinate lines ruled parallel to the short edge of the paper provide for the time scale, and those parallel to the long edge provide for the height scale.

54. The time scale is uniformly 0.4 inch to the hour and the hour lines are so spaced. The hour spaces are subdivided by lighter lines into six equal parts to represent 10-minute intervals. The length of each sheet is sufficient to include 48 hours which are numbered in two sets from 0 (midnight) to 23 (11 p. m.). The height scale ruling varies according to the scale with which the gage is to be operated as indicated by the table on page 23, provisions being made for five different scales. For the smallest scale, 1:45, the sheets are ruled for feet and half-feet, but for all other scales the foot spaces are subdivided into five parts, each representing 0.2 foot. Printed on the margin of each sheet is a note indicating the height scale of the paper and the correct gears to be used with the same.

55. Originally the paper provided with the gage was finished with ordinary sizing for use with pencil or ink, neither of which was entirely satisfactory. The difficulty with the use of ink was due to the large changes in humidity to which a tide station is exposed. Because of the effect of excessive moisture on ordinary record paper it was found impossible to obtain an ink which would give satisfactory results under all conditions. To overcome this difficulty there is now used a wax-coated paper on which the record is traced by a stylus which removes the wax coating leaving exposed a colored paper beneath.

56. Float wire.—The wire used for this gage may be either phosphor-bronze or nickel-chromium. Size No. 28, American wire gage, is required to fit the grooved thread on the float drum. This is a little finer than that used for the standard tide gage.

57. Float.—The float (13, fig. 11) designed for use with the portable tide gage is a hollow brass cylinder 3¼ inches in diameter and 15 inches long. It is weighted with shot to float with the upper end about 3½ inches above the surface in sea water or about ½ inch above the surface in kerosene. The float was especially designed for use in a 3½- or 4-inch float well. The gage may also be operated with a larger diameter float in a larger well.

58. Float pipe.—There is furnished with the gage a short section of 4-inch pipe 7 inches long (2, fig. 11). The upper end is machined to fit into the socket in the base of gage and is secured to the latter by two screw hooks (27, fig. 13) which engage in small rectangular holes near the top end of the pipe. The lower end is threaded to form a union with additional lengths of pipe required for the float well. The gages were formerly designed for use with a 3½-inch pipe, and in order to adapt the earlier gages for use with a 4-inch float well reducing couplings are necessary.

59. Intake coupling.—A conical intake coupling (16, fig. 11) is furnished as one of the regular accessories to the portable tide gage. This is installed with the apex of the cone downward. The cylindri-

cal part is threaded inside to serve as a coupling between the float well proper and a supporting section of pipe (fig. 14). In the apex of the cone there is a threaded 1-inch hole in which may be fitted a bushing with a smooth bore intake opening of the size desired. Bushings with openings ½ inch, ⅝ inch, and ¾ inch are provided with the gage.

60. **Cleaning tool.**—A special tool (15, fig.11) is furnished with the portable gage for use in cleaning the intake to the float well. This consists of a cylindrical weight about 1½ inches in diameter and 5 inches long containing in the bottom a pointed shank about ¼ inch in diameter and 2 inches long. At the top is an eye for the attachment of a line.

PRIMARY TIDE STATION

61. A primary tide station is one that is maintained over a period of several years to obtain a continuous record of the tide in any locality. As the records from such a station constitute basic tidal data for present and future use, it is very important that the installation and maintenance of the station should be with the aim of obtaining the highest degree of reliability and precision that is practicable. The essential equipment of a primary tide station includes an automatic tide gage, float well, shelter, tide staff or equivalent float-gage, and a system of bench marks.

LOCATION

62. Special care should be taken in the selection of a site for a primary tide station. If possible, there should be a depth of not less than 5 feet below the probable lowest tide. This is especially desirable in cold climates where kerosene is used in the float well to prevent freezing, and also in exposed locations where storm waves of large amplitude are common. When the determination of the height of mean sea level is an important aim, the station should be located on the open coast or in a bay with ample access of sea water. A river or bay connected with the sea by a relatively small inlet is not a suitable location for this purpose because of the probable difference in the mean water level inside of the inlet and on the outer coast. A place separated by a bar from the main body of water should in general be avoided less the records obtained will not be representative of the tidal conditions in the general area.

63. In selecting the site for a primary tide station it is very desirable that attention be given to the cleanliness of the surroundings. Highly congested areas with a large amount of shipping should in general be avoided. Because of the commercial need for space in such areas, quarters obtainable for a tide station are usually cramped and poorly lighted and ventilated. These conditions, together with the presence of more or less refuse in the adjacent waters with accompanying offensive odors, tend to discourage the proper care of the gage by the observer. Moreover, in such areas both the automatic gage and tide staff are subject to dangers of disturbance from the docking and loading of vessels. Especially, the tide staff may be accidentally knocked out of place and resecured at a different elevation without any report of the incident. Heavy vehicular traffic in such an area also renders the leveling between tide staff and bench marks especially difficult.

64. On the other hand, a tide station located some distance from a congested area, where the tide is equally representative of the general region, will be freer from these disadvantages and be no less accessible to the tide observer. In general, a Federal, State, or municipal wharf is preferable to a private one; but a pier maintained for public amusement and recreation often affords an ideal location for a primary tide station.

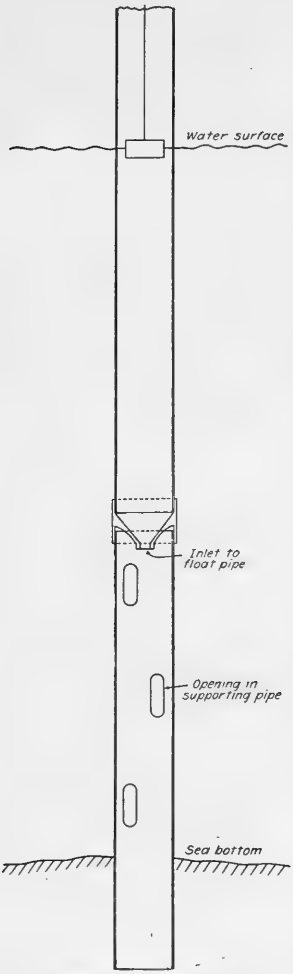

FIGURE 14.—Float well.

FLOAT WELL

65. The float well is a vertical tube or box with an opening in the bottom designed to admit the tide to a float operating the gage while dampening out the larger waves caused by winds. The float wells now generally used by this survey are constructed either of iron or of wood. For exposed locations on the outer coast the iron float well is used on account of its strength, but for more quiet waters a float well constructed of wood and covered on the outside with sheet copper is more economical in construction and installation and will last many years. In cold climates which require the use of kerosene in the well to prevent freezing, the iron well has the advantage of retaining the kerosene without leakage over a long period of time.

66. Iron float well.—The iron float well (fig. 14) is usually made up of sections of stock pipe. The usual installation when the depth is not too great consists of a supporting section below the intake and extending several feet into the ground and containing large openings in the sides to admit the tide to the intake. Above the intake a sufficient number of pipe sections are used to extend the top several inches above the floor of the tide house. A special intake coupling (fig. 15) forms a union between the supporting section and the pipe above. If possible, the section immediately above the intake should be sufficiently long to extend above high water in order that there may be no rough joints for the float to catch on and to provide an oil-tight section for kerosene when this is necessary to prevent freezing. Flange couplings may be used for connecting pipe sections above high water. While such joints are not as durable as sleeve couplings because of the tendency for the connecting bolts to corrode, they add greatly to the convenience of installation and the bolts when above high water may be easily renewed from time to time.

67. For a primary tide station 12-inch pipe is recommended. When a supporting section is used, this should contain six large openings, each about 3 inches wide by 9 inches long and arranged in pairs on

opposite sides of the pipe and facing in different directions. The center of the upper pair should be about 1 foot below the top of this section of pipe and the others arranged with centers approximating 3 and 5 feet below the top of the section.

68. Wooden float well.—A wooden float well for use at a primary tide station should usually be constructed of 2-inch by 14-inch planks so assembled to form a box 12 inches square on the inside and long enough to reach from the floor of the wharf to several feet below the lowest tides. A sloping bottom with intake in one of the lower corners should be provided, the corresponding corner at the top being marked for identification, preferably by beveling off the corner. When the depth of water is not too great, two opposite sides of the box may be extended below the intake to rest as a support upon the sea bottom. The outside of the float well should be covered with 16-ounce sheet copper from the bottom to a height above mean high water as a protection against teredos and other marine animals, copper nails being used in construction of the well as a precaution against electrolytic action between nails and copper sheathing.

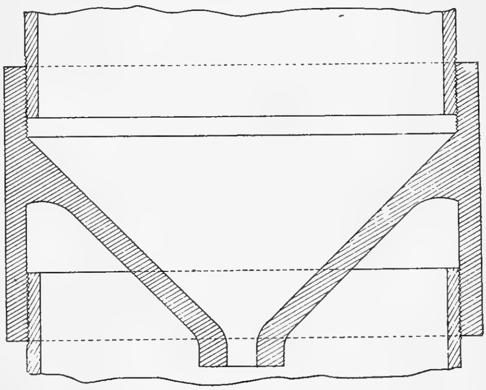

FIGURE 15.—Intake coupling for float well.

69. Intake.—The intake to the float well should be of sufficient size to permit the free access of the tide while damping down the effect of heavy seas. The opening must, however, be large enough so that rough water on the outside will always leave an unmistakable trace upon the tide record. In protected localities an intake 1½ inches in diameter is recommended for a 12-inch float well, but for places exposed to heavy seas an intake from ¾ to 1 inch is sufficient. A single large intake is to be preferred to several small ones, as the former is less likely to become clogged and is more easily cleaned when clogged. An intake should be in the bottom of the float well rather than in the side to facilitate cleaning. For an iron float well a special conical intake coupling is provided, and when installed this is placed with the apex downward. For a wooden float well a square hole may be sawed in one corner of the bottom before assembling the parts. At the time of the installation of a primary tide station facilities should be provided for the periodic cleaning of the intake by the tide observer. (See pars. 132–135.)

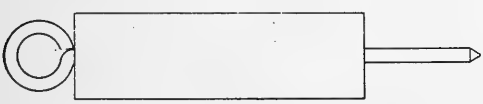

FIGURE 16.—Cleaning tool for float well.

70. Installation of float well.—Special care must be taken to secure the float well in a vertical position in order that the float may rise and fall freely without scraping the sides of the well. Where sufficient depth is available, the well should be installed with the intake

from 5 to 6 feet below the lowest probable tide. It is desirable, however, that there be sufficient depth below the intake to make it unlikely that it will become covered by a shoaling of the water in the vicinity. It is desirable that the top of the well extend several inches above the floor of the tide house for convenience of access and also to lessen the chance of objects on the floor accidentally falling into the well. For an iron float well, a flanged collar at the top may be arranged to rest upon iron plates secured to the floor of the wharf. The well should be strongly braced in position.

71. Precaution against freezing.—In cold climates kerosene is generally used in float wells to prevent freezing. The column of kerosene should be from 2 to 5 feet in height, depending upon the severity of the winters. A 12-inch cylindrical pipe will require about 6 gallons of kerosene for each foot of height and a 12-inch square float well about 7½ gallons for each foot of height. The amount of kerosene which can be retained in the float well will be limited by the depth of the intake below the lowest tide. When an iron float well is used and the intake is sufficiently low, the kerosene introduced at the time of installation may remain for many years, the loss from evaporation being small. In a wooden float well there is more or less leakage and the supply of kerosene must be renewed at frequent intervals.

72. As the specific gravity of kerosene is less than that of water, the surface of the kerosene in the float well will stand above the water level outside, the difference in level being approximately equal to one-eighth the entire height of the column of kerosene. Note should therefore be entered in the record whenever kerosene is introduced into the well and a comparative staff reading taken before and after this is done. In the tabulation of the automatic tide gage record, the effect of this height difference is eliminated in the computations involving the comparative staff readings. *It is very important, however, that no kerosene shall be used in a float well designed for a tape gage or other nonregistering float gage the readings from which are to be taken directly, as errors of indeterminate amounts may thus be introduced.*

TIDE HOUSE

73. When sufficient space is available, the tide house should be approximately 6 feet square and from 7 to 8 feet high. A house of this size provides room for the tide observer to move around the gage and give it such attention as may be required. The house should be well lighted by windows, neat in appearance, and painted to conform with other buildings in the immediate vicinity. A standard sign with the following inscription will be provided upon requisition:

U. S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
TIDE STATION

74. The tide house will in general be placed over the top of the float well so that the wire from the gage may be led directly to the automatic tide gage. When this arrangement is impracticable, the float wire may be led from the float well over a system of pulleys and through a suitable conduit to the gage in the tide house. When this

is necessary, facilities should be provided for the convenient replacement of a broken float wire by the tide observer. The top of the float well must be provided with a suitable cover as a precaution against the accidental dropping of anything into it.

75. A table or shelf must be provided for the support of the tide gage. A shelf can be conveniently constructed by setting the shipping box of the tide gage on one end and then laying boards from this to a cleat nailed to the wall of the tide house. The box and boards are secured by screws which may be easily removed when it is necessary to dismantle the gage. By hinging the cover of the shipping box a convenient cupboard is formed for the storage of extra tide rolls and other small articles.

INSTALLATION OF TIDE STAFF

76. Each primary tide station must be equipped with a tide staff or equivalent tape gage to provide a temporary datum and reference scale for the automatic gage record. The tide staff, which is described on page 2, is to be used in preference to a tape gage when practicable. In selecting the location for the tide staff consideration should be given to convenience in taking accurate readings and also in leveling between staff and bench marks. The staff must be reasonably near the automatic gage to avoid any long delay between the reading of the staff and the recording of the reading on the automatic gage record, and should be placed so that the graduations are clearly visible to the tide observer from an easily accessible position.

77. Special attention should be given to placing the tide staff so that its elevation may be conveniently checked by levels to bench marks. There should be sufficient clearance above the staff to hold the leveling rod in a vertical position. Sometimes a fixed tide staff can be so located that it can be sighted upon directly from a leveling instrument set up on the shore; but when this is possible only during low water, other arrangements should be made in order that a leveling party may not be unduly delayed by an unfavorable stage of the tide.

78. When installing a tide staff care must be taken to secure it in a vertical position. The piling of a wharf often offers a convenient support for a tide staff, but if an inclined pile is used for the purpose offsets must be provided to keep the staff vertical. At the time of the original installation, the exact elevation of the staff zero is usually unimportant and it is the general aim to place the zero sufficiently low to avoid frequent negative readings. However, if it is desired to set the zero at some previously determined datum, such as mean low water, the staff graduations must extend negatively below the zero. After installation it is very important that the zero be maintained at a fixed elevation, and any known or suspected change should be reported to the office.

INSTALLATION OF TAPE GAGE

79. In exposed localities where rough water renders the use of a tide staff impracticable, a nonregistering float gage may be substituted for the staff. The most satisfactory gage of this type now in use by this office is a tape gage (fig. 2) with a graduated steel

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tape attached to an 8½-inch float operating in a 12-inch float well. The reading mark should be a well-defined line on a board just back of the tape and from 4½ to 5 feet above the floor for convenient reading by the observer. This reading line may be engraved on a metal plate screwed fast to a board or it may be defined by the slot in the head of a brass screw placed in the board close to the tape. The counterpoise of the tape gage should be attached to a movable pulley to increase the range of operation otherwise limited by the height of the tide house ceiling.

80. To facilitate the determination of the plane of flotation and also to provide greater durability, it is recommended that the bottom portion of the tape which remains below the wharf floor during all stages of the tide be a detachable piece of phosphor-bronze tape. The work of determining the plane of flotation will be further facilitated by installing a secondary reading board about 18 inches above the level of the floor with a horizontal line from the tape to a distance a little greater than the radius of the float.

81. The float well for the tape gage may be similar to the one used for the automatic gage (page 26). The size of the intake should not be less than that indicated for the automatic gage and must be large enough to show a perceptible motion in the tape when the outside water is moderately rough. When installing the float special care must be taken to arrange the supporting pulley so that the float will swing clear of the sides of the well at all stages of the tide.

82. Determination of plane of flotation.—To establish directly the relation of the datum of the tape gage to bench marks it is necessary to determine the plane of flotation of the tape gage float under normal operating conditions. This is accomplished by placing the float in a pan or bucket of water of the same density as that in the float well and measuring the distance from the water surface to some graduation of the tape. The pan is placed over the top of the float well and the float must be connected with its counterpoise. In order that the counterpoise may swing clear of the floor, surplus tape may be folded into several loops, avoiding sharp bends, and tied together with a cord. If the tape contains a detachable portion, this may be removed and placed in a coil on top of the float in order that its weight may be included in the determination of the plane of flotation. The length of the removed section must afterwards be taken into account in obtaining the relation of the plane to the scale graduations.

83. The float must be moved slowly up and down and allowed to come to rest from both the upward and downward movement to ascertain any difference in tape reading due to friction in the supporting pulleys. If any difference is noted the float should be placed with the mean of the two tape readings at the reading mark. Careful measurements should now be taken of the vertical distance from the water surface in the pan to some graduation on the tape, which requires that the line of the tape graduation be extended horizontally over the float to a point above the water surface. This may be conveniently done by having a horizontal line drawn on the reading board or on a similar board arranged closer to the floor of

the tide house for the purpose. The measured distance added to the tape graduation to which the measurement was made, together with an allowance for any detached section of tape, will give the plane of flotation as referred to the tape graduations extended. It is also the distance which the tape gage datum is below the reading mark of the gage. The result, however, is subject to a small correction described in the following paragraph.

84. Correction to plane of flotation.—The necessity for this correction arises from the fact that the shifting of the tape from one side of the supporting pulley to the other may make a slight difference in the plane of flotation. Although the variation is too small to be of material importance in taking readings during the normal operation of the gage, it is desirable that in a careful determination of the plane of flotation under conditions differing from the normal, a correction shall be applied to reduce the measurement to a mean sea level reading. The correction will depend upon the weight of the tape, the diameter of the float, and whether the counterpoise is attached directly to the end of the tape or supported by a movable pulley.

85. In order to make this reduction, the tape reading taken at the reading mark at the time the measurements are made should be noted. In taking this reading it is assumed that the looped portion of the tape is below the reading mark.

Let R' = tape reading at time of measurement.
R = tape reading corresponding to mean sea level.
D = diameter of float in inches.
t = weight of tape per linear foot.
W = weight of a cubic foot of water at tide station.

The cross section of the float is $\frac{\pi D^2}{576}$ square feet and the buoyancy due to an immersion of 1 foot of a cylinder of the same diameter is $\frac{\pi W D^2}{576}$ pounds. Therefore, when the float is operating under normal conditions, an application of a force of 1 pound would change the plane of flotation by $\frac{576}{\pi W D^2}$ feet. When the apparatus is arranged as in figure 2 with the counterpoise supported by a movable pulley, the shifting of 1 linear foot of tape from one side of the supporting pulley to the other side will cause a change of $1\frac{1}{2}\,t$ pounds in the pull on the float and the plane of flotation will be changed by $\frac{864\,t}{\pi W D^2}$ foot. The total correction to be applied to the plane of flotation as obtained by direct measurement, in order to reduce to the mean sea level value, is $\frac{864\,t}{\pi W D^2}\,(R-R')$ foot.

86. Taking the average weight of sea water as 64 pounds per cubic foot, the weight of steel and phosphor-bronze tape, respectively, as 0.0071 pound and 0.011 pound per linear foot, and assuming the diameter of the float to be either $8\frac{1}{2}$ or $3\frac{1}{4}$ inches, there have been

computed the following factors which when applied to the difference $(R-R')$ will give the necessary correction to the plane of flotation:

	8½-inch float	3¼-inch float
Steel tape with counterpoise on movable pulley	0. 00042	0. 0029
Steel tape with counterpoise on end of tape	. 00056	. 0039
Phosphor-bronze tape with counterpoise on movable pulley	. 00065	. 0045
Phosphor-bronze tape with counterpoise on end of tape	. 00087	. 0060

As the correction varies directly as the weight of the tape and inversely as the square of the diameter of the float, corresponding corrections for floats of other sizes or for tapes of different weight may be readily derived from the above values. For example, the correcting factor for a 9½-inch float with steel tape and movable pulley is

$$0.00042\times(8\tfrac{1}{2})^2/(9\tfrac{1}{2})^2=0.00034.$$

INSTALLATION OF STANDARD AUTOMATIC TIDE GAGE

87. Preparatory to the installation of the tide gage, the instrument should be carefully checked to see that all parts are in satisfactory working order. The scale of the gage and the corresponding float drum will depend upon the extreme range of tide at the locality and will be selected in accordance with the table in paragraph 39. Special attention must be given to the pencil screw to see that the pencil arm moves freely along its entire length and that the arm is properly released on reaching each end of the screw thread and automatically returned to the thread through the action of the return springs when the direction of rotation is reversed. In the latest type of gage, the pencil screw may be removed from the gage and rotated by hand while the pencil arm is hanging freely by its own weight. Any tendency for the arm to swing upward with the rotation of the screw should be investigated and steps taken to remove the cause of any sticking until all perceptible resistance to a free movement of the arm along the screw has been eliminated. Special attention should also be given to the hour-marking device to see that it is functioning satisfactorily and such adjustments are made as may be necessary. (See pars. 127–128.)

88. Setting up automatic tide gage.—The standard installation, in which both counterpoise and tension weights are supported by movable pulleys, is illustrated in figure 17. When practicable, the gage is to be placed on a table or shelf over the float well so that the float may be suspended directly from its drum without any intervening pulleys. By means of a plumb line or the temporary installation of the float, the position of the gage should then be adjusted to center the float in the well. In doing this, consideration must be given to the possibility that the well may not be exactly plumb and the centering should be done at the water level rather than at the top of the well.

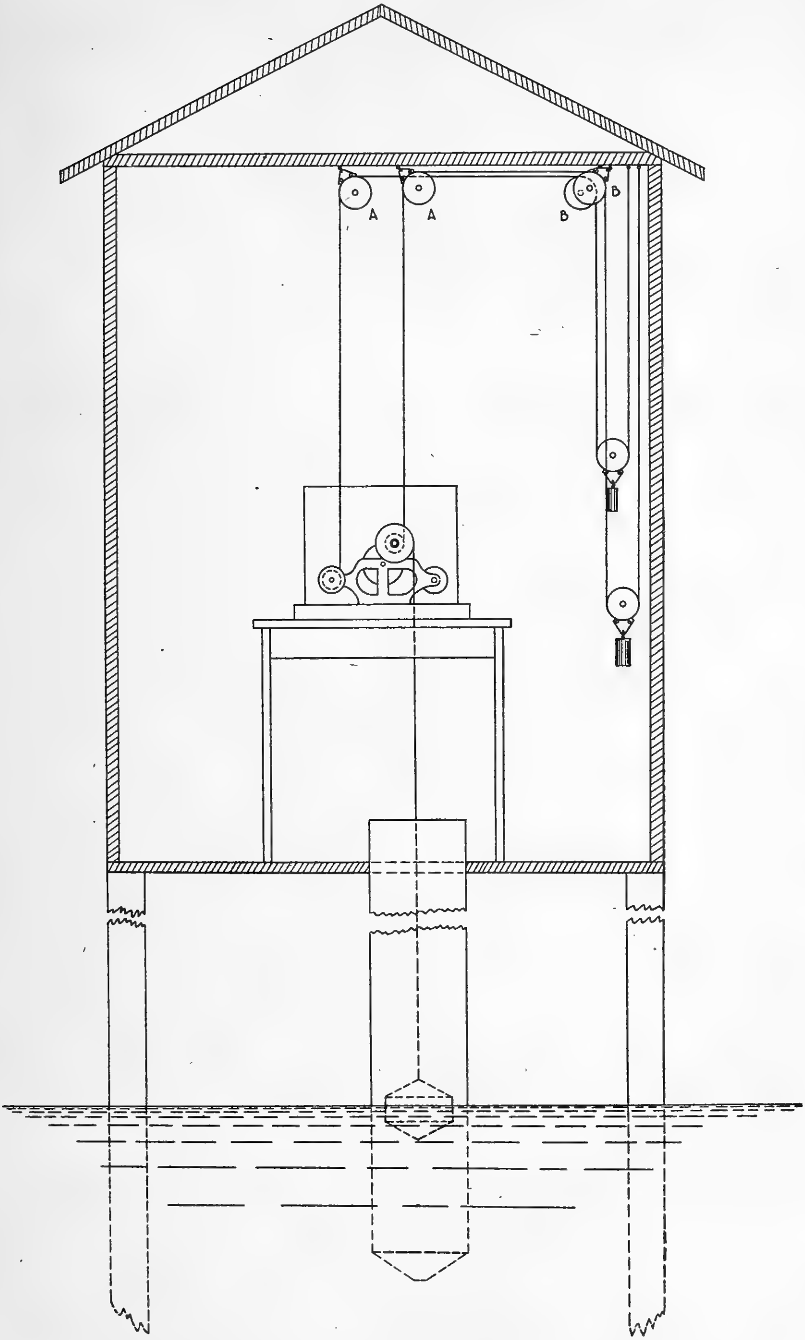

FIGURE 17.—Schematic view of installation of standard automatic tide gage.

89. Installation of pulleys.—The standard pulley now used for the counterpoise wire and tension weight cord are 4 inches in diameter and weigh 1 pound each. For the arrangement illustrated in figure 17, six such pulleys are required, two being used as movable pulleys attached to the weights and the other four as fixed pulleys which are secured to the ceiling of the tide house by screw eyes. Under operating conditions the fixed pulleys do not hang vertically but are deflected by an amount depending upon the weight of the pulley itself and the strain on the wire or cord. In order that the wire may pass vertically upward from the gage and also to provide for parallelism in the strands supporting the movable pulley and weight, it is necessary to make allowances for the deflection of the fixed pulleys when securing them in position. Computations depending upon the counterpoise weights used with different float drums have been made and the results are given in the table below. In these computations the distance from the center of the pulley sheave to the end of the supporting hook is taken as 4 inches and a small allowance has been made for the depth of the groove in the sheave.

Float drum	6-inch	9-inch	12-inch	16-inch	24-inch
Counterpoise weight	1 lb.	2 lb.	3 lb.	4 lb.	6 lb.
Counterpoise with pulley	2 lb.	3 lb.	4 lb.	5 lb.	7 lb.
Counterpoise wire tension	1 lb.	1½ lb.	2 lb.	2½ lb.	3½ lb.
Float wire tension	1 lb.	1 lb.	1 lb.	15 oz.	14 oz.
Offset, pulley-A	+⅛ inch	−⅛ inch	−¼ inch	−⅜ inch	−½ inch.
Offset, pulley-B	4 inches	3¾ inches	3½ inches	3⅜ inches	3¼ inches.

The offset of pulley-A for the counterpoise wire indicates the position of the screw eye for the support of the fixed pulley immediately above the gage as measured from a point in the ceiling in a vertical tangent to the counterpoise drum on the side from which the wire is led. The measurement is to be made in the direction toward which the wire leads if preceded by the plus sign and in the reverse direction if preceded by a minus sign. The offset of pulley-B indicates the position of the screw eye for the second pulley as measured from the point of attachment of the fixed end of the wire, the latter being in line with the two fixed pulleys. Measurements for the installation of the pulleys for the tension weight cord are made in a similar manner, the offsets being those corresponding to the 6-inch float drum, provided that a 1-pound tension weight is used. In this case the first offset is measured from a point vertically above the tension weight drum.

90. In order that the gage may be operated to its full capacity in recording extreme ranges of tide, it should be the aim to have the adjustment such that at approximate mid-extreme tide level the float drum and counterpoise drum will each be half filled with wire, the counterpoise half way between the limits of its motion, and the recording pencil near the middle of the main roller. As the larger of the counterpoise drums contains 14 feet of wire when filled, a fall of 7 feet for the counterpoise weight as supported by a movable pulley will be sufficient for the maximum limits of the gage operation. These limits would require a ceiling height of approximately 8 feet including an allowance of 1 foot for the combined length of the counterpoise

weight and supporting pulley. The extreme limit, however, will seldom be required, and a ceiling height of 6½ to 7 feet will in general be ample for the operation of the gage. On the open coast the mid-extreme tide may be taken as approximately the same as mean sea level; but in rivers the height above mean river level reached by the extreme high waters is usually much greater than the depth to which the extreme low waters fall. However, in estimating the mid-extreme tide for the adjustment of the gage, no consideration need be given to a high-water height that is above the bottom of the tide gage or to a low water that is below the bottom of the float well, since beyond these limits the gage would cease to function regardless of adjustment. (See par. 119.)

91. Attaching counterpoise.—The weight of the counterpoise depends upon the size of the float drum and is to be selected in accordance with the table in paragraph 89. In the standard installation the counterpoise is used with a movable pulley, but if it is attached directly to the end of the counterpoise wire, its weight should be one-half the tabular value given for the combined counterpoise and pulley. Before installing the counterpoise, the pencil screw should be removed from the gage (par. 29) and the float drum released (par. 34) so that this drum and the counterpoise drum may be turned independently of each other. For the older type of instrument which does not permit the easy removal of the pencil screw, this screw should be rotated until the pencil arm has cleared the screw thread at the end nearest the clock case. Following the scheme of installation illustrated in figure 17, the necessary fixed pulleys being secured to the ceiling of the tide house and the counterpoise fastened to a movable pulley, the wire (par. 35) is passed through the fixed and movable pulleys and one end attached to a screw eye provided for the purpose in the ceiling of the tide house. The wire is then cut of such length that the counterpoise will hang just clear of the floor as the free end of the wire is attached to the counterpoise drum. A small hole or clamp near the edge of the drum is provided for this attachment.

92. Attaching float.—The proper float drum for the range of tide having been selected from the table in paragraph 39, the length of wire to be wound upon this drum at the time of installation will depend upon the stage of the tide. Let L equal length of wire to be wound upon the drum at time of installation, C the length of wire necessary to half fill the drum, and H the height of tide at time of installation referred to the mid-extreme tide level, H being negative if water surface is below this level, then $L=C+H$ for the required length.

The value for C for drums 1⅛ and 1¾ inches wide may be taken from the following table:

Circumference of float drum in inches	6	9	12	16	24
Width of drum:	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1⅛	4½	6¾	9	12	18
1¾	7	10½	14	18⅔	28

Unless previous tide observations have been taken in the locality the value for H must be estimated. From best information available ascertain the approximate heights reached by the highest and lowest tides and then note the height of the water surface at the time of installation as compared with a plane midway between the estimated highest and lowest, taking H as positive if the surface is above mid-extreme level and negative if below this level.

93. Before installing the float it is a good plan to pass several loose loops of wire through the supporting ring to aid in its recovery from the float well if the float wire becomes accidentally broken. Next, taking a spool of wire, attach one end of wire to the float and lower it into the well until it comes to rest on the surface of water or kerosene. Lead the wire to the float drum of the gage and, after measuring off an additional distance equal to L as determined from the formula in the preceding paragraph, cut the wire from the spool and attach the end of the wire to the float drum by passing it through a small hole near the outer edge and knotting it.

94. If the gage is of the latest type, with removable pencil screw, wind up the float wire by turning the float drum on its shaft until all threads on the drum are filled or until the float has reached its upper limit of motion. When doing this the counterpoise drum is left undisturbed with the counterpoise hanging close to the floor. Both drums are then secured rigidly to the drum shaft by tightening the capstan lock nuts on the two sides. The float is then allowed to descend slowly until it rests upon the surface of the water in the well. As the float descends it automatically winds up the counterpoise wire on its drum. The pencil screw may now be replaced on the gage with the pencil arm set to bring the record curve near the middle of the paper, consideration being given to the present stage of the tide in its relation to the mid-extreme tide.

94a. The following instructions apply only to the old type gage without removable pencil screw. Having determined the proper length of wire in accordance with paragraphs 92–93, remove the float drum entirely from the gage and wind the float wire upon it, raising the float as necessary, until all the threads on the surface of the drum are filled or until the float has reached its upper limit of motion. Replace the drum on the gage and secure it with the two clamping nuts provided for the purpose, but holding it carefully against the sudden falling of the float. Next, holding the pencil arm to one side to keep it from immediately engaging the threads of the pencil screw, allow the float to descend slowly. With a gage equipped with a pencil screw of 1-inch pitch, release the pencil arm after 2½ turns if the drum is 1⅛ inches wide, or after 7½ turns if the drum is 1¾ inches wide. With the pencil screw of ½-inch pitch, release the pencil arm immediately for the drum 1⅛ inches wide or after 1½ turns for the drum 1¾ inches wide. After the release of the pencil arm let the float continue to descend slowly until it rests upon the water or kerosene in the well. The lowering of the float automatically winds up the counterpoise wire and moves the pencil arm approximately to its correct position. If any further adjustment of the position of the pencil arm is necessary, it may be accomplished by loosening the clamping nuts holding the float drum and turning the pencil screw

as desired. In doing this, care must be taken to hold the counterpoise drum against the pull of the counterpoise weight and also to press the float wire against its drum to keep it from springing off as the wire slackens.

95. Attaching tension weight.—In general it is best to have the tension weight operate from a movable pulley (fig. 17) to reduce the rate of fall. When thus suspended, the weight will descended on an average about 1 foot a day but the rate will vary with the amount of paper on the receiving roller. Place the weight with pulley attached on the floor at the lowest limit of its motion. After installing the necessary fixed pulleys in the ceiling of the tide house, take a spool of cord and pass one end of the cord through the fixed pulleys down through the movable pulley attached to the weight, and then secure the end to a screw eye in the ceiling. Next unwind enough additional cord to reach to the tension drum on the gage and cut from the spool. Pass the end of the cord through the small hole provided for the purpose and secure by knotting. The cord is now ready to wind upon the drum as soon as the record paper is installed.

96. Starting the gage.—The gage is now ready for the installation of the paper (pars. 115–116), adjustment of pencils (pars. 118–119) and entry of comparative note (pars. 120–126), these processes being described in detail under "Operation of tide station." Both springs on each clock should be wound. If the care of the gage is to be turned over to a new observer, he should be given such preliminary instructions as will aid him in interpreting the printed instructions in this volume.

TIDAL BENCH MARKS

97. An essential part of the establishment of a tide station is the installation of a system of bench marks to which the observed tides may be ultimately referred. A bench mark may be defined as a definite point on a more or less permanent object used as a reference for elevations. Bench marks established in the vicinity of a tide station for the purpose of preserving tidal planes determined from the observations are known as "tidal bench marks." These bench marks serve as the basis for elevations which are carried by levels to numerous other bench marks established in various parts of the country.

98. Qualities.—The two principal qualities desired in bench marks are permanency and certainty in identification, and these qualities should be kept in mind when establishing new bench marks. In a settled community substantial buildings afford excellent locations for the establishment of bench marks. In an undeveloped country a ledge of rocks or a mass of concrete partly buried will serve as a suitable foundation. Except for temporary use only, bench marks should not be located on hydrants, curbstones, trees, or any structure especially liable to destruction or change in elevation.

99. Standard disks.—Certainty in identification can be best obtained by the standard Coast and Geodetic Survey disk bench marks (fig. 18) and these should always be used when possible. The disk, which is made of copper alloy, is 3½ inches in diameter and contains the inscription "U. S. Coast and Geodetic Survey Bench Mark" together with other information. It contains a shank for cementing

in place. The number of the mark and the year of establishment should be stamped on the disk. Duplications of numbers should be avoided and a number previously assigned to another bench mark in the same locality, whether destroyed or extant, should not be used for a new mark. Sets of dies for stamping letters and figures can be obtained upon requisition.

100. Bench marks on buildings.—In a town or city, the post office, customhouse, city hall, schools, railroad stations, banks, and other

FIGURE 18.—Standard disk tidal bench mark.

substantial public and business buildings generally afford the best locations for bench marks. Buildings with foundations of questionable stability should be avoided. Permission will usually be granted for the installation of the standard disk bench mark on such buildings as may be selected when the use of the same is explained to the authorities in control.

101. General permission for the establishment of bench marks on Federal buildings is contained in the following authorization:

TREASURY DEPARTMENT,
Washington, November 11, 1914.

The honorable the SECRETARY OF COMMERCE,
Washington, D. C.

SIR: By direction of the Secretary, I have the honor to acknowledge the receipt of your communication of the 7th instant, requesting that permission be granted to the officers of the Coast and Geodetic Survey to place on the Federal buildings under the control of this department small inscribed metal tablets, which are to be used as bench marks in connection with the system of leveling, the custodians of the buildings to designate where the tablets are to be placed.

In reply you are advised that no objection will be interposed by this department to the placing of the tablets on the various public buildings, as desired, and this letter, or a copy thereof, upon its presentation to the custodian of a Federal building, is to be considered by him as his authority for permitting the placing of one of the tablets on the building in his custody.

Respectfully,

(Signed) B. R. NEWTON,
Assistant Secretary.

102. When a suitable place can be found, it is in general desirable to set the face of the bench mark disk horizontal for convenience in holding the leveling rod, but there should be sufficient clearance above the bench mark for the rod used in the first-order leveling, which is approximately 11 feet long. Sometimes greater permanency can be secured by placing the bench mark in the vertical wall of a building. In this position the short horizontal line through the center of disk becomes the bench mark and a graduated tape may be substituted for the rod in making the leveling connections. A bench mark in a vertical wall should be several feet above the ground for convenience in holding the tape used by the leveling party. Care should be taken to set the disk with the reference line horizontal. The bench mark is to be countersunk with its face flush with the wall, and when set in a conspicuous place special care must be taken to have the work neatly done so that the building will not be defaced.

103. Bench marks in rock.—Rocky outcrops and boulders in areas not likely to be disturbed for many years make satisfactory locations for bench marks. If a boulder is used the bottom should extend far enough below the surface of the ground so that it will not be affected by action of frost. The standard disk should be cemented in place with its face horizontal and countersunk.

104. Bench marks in concrete.—Where a suitable building or natural rock is not available, the bench mark disk may be set in a concrete monument built in the place desired. The monument should extend not less than 3 feet below the surface of the ground, and in localities having severe winters the depth should be sufficient to withstand frost action. In general the top will extend several inches above the ground in order that it may be readily found when needed. The base should have a cross section greater than the top and there must be no projecting edges which might provide leverage points for frost action. If the monument is in the form of a frustum of a cone or pyramid, the sides should have a batter of not less than 1 inch to the foot. A convenient shape for making the concrete monument is a series of square blocks from 8 to 12 inches thick, the bottom block being about 18 inches square and successive blocks of diminishing cross section with the top block about 12 inches square.

105. It is important in making the concrete that all materials be clean and thoroughly mixed before adding water. It should not be too wet and should be well tamped into the mold. When using rough aggregate the proportion should be about 1:3:5, the upper part of the mass to be of a richer mixture. When only sand and cement are obtainable the proportion of 1 part of cement to 3 parts of sand should be used for the lower part of the mass and 1 part of cement to 2 parts of sand for the upper part. To prevent rapid drying of the concrete, its surface should be covered with dampened paper or cloth or wet seaweed held in place with earth.

106. Number of bench marks.—To insure against loss of datum, there should be a number of bench marks widely scattered but in general within a radius of 1 mile from the tide station. For all series of tide observations, no matter how short, there should be a reference to at least three substantial bench marks. The minimum requirement for a series of observations covering a year or more is

five bench marks. For a primary tide station which is to be maintained over a long period of years ten substantial bench marks may be considered as adequate.

107. Primary bench mark.—At each principal tide station there is usually one bench mark, known as the "primary bench mark," which is selected for its stability and convenience of location and is used in checking the elevation of the zero of the tide staff from time to time, so that if any change takes place the proper allowance may be made in the tabulations. The stability of the primary bench mark is in turn checked by levels to a number of other bench marks which are so located that their elevations will not be likely to be changed by a common cause.

108. Basic bench mark.—The basic bench mark used by the Coast and Geodetic Survey consists of one of the standard disks set in top of a concrete monument which extends about 2 feet above the ground. The monument contains the inscription "United States Coast and Geodetic Survey Basic Bench Mark" on one side and rests upon a reinforced concrete foundation with an enlarged base extending a number of feet below the ground.

109. Descriptions.—Full descriptions of all bench marks must be carefully prepared and forwarded to the office with form 258, leveling record—tide station. The descriptions should be clear and distinct and sufficiently complete to enable the bench marks to be readily recovered and identified. If a standard disk is used, the description must include a definite statement whether the number of the mark, the year of establishment, and its elevation have been stamped in the metal. When a bench mark is located on a building, the street and number should be given when possible, or the name of the owner. When not on a prominent structure a bench mark should be referenced by distance and direction to several prominent objects. A sketch which will aid in locating or identifying the bench mark is desirable.

110. Leveling.—At the time of the establishment of a tide station and at intervals thereafter the tide staff must be connected with the bench marks by levels. If possible, all bench marks within a radius of 1 mile of the tide station should be connected with the tide staff at intervals not greater than 5 years, but it is desirable that the staff be connected with not less than three bench marks including the primary bench mark each year or at more frequent intervals, in order that any change in the elevation of the tide staff may be detected without unnecessary delay. It is also desirable that bench marks of other organizations which may be in the vicinity should be connected from time to time with the bench marks of this Survey.

111. The graduating lines on the tide staff now in use have a width of about 0.01 foot. The middle of each line is to be taken as the reference for heights on the staff. If a portable tide staff is used at the station, the leveling rod should be held on the flat top of the brass plate on top of the tide staff support, and the reading on the tide staff to which this plate corresponds must be entered in the record. This staff reading is determined by the position of the metal stop attached to the back of the staff. It is important, however, that the staff be placed in its support to see that this stop comes in actual contact with the plate on the support without interference

from any obstruction. When a tape gage is used at the station, levels must be run from the reading mark of the gage to the bench marks, the relation of this reading mark to the tape gage datum being determined from the position of the plane of flotation (pars. 82–86).

112. Before beginning the leveling care must be taken to have the instrument in adjustment and also to see that the bottom of the leveling rod corresponds exactly with the zero of the graduations. The latter is important if some sights are to be taken directly on the tide staff or on a graduated tape. Foresights and backsights should be approximately equal. The leveling between the marks must be checked by a forward and a backward line and the closing error in feet must not exceed $0.035\sqrt{K}$, in which K is the distance in statute miles leveled between adjacent bench marks. For convenience of use the following table is given:

Distance between bench marks (feet)	Maximum error allowed	Distance between bench marks (feet)	Maximum error allowed
	Foot		*Foot*
500 or less	0.011	3,000	0.027
1,000	.015	4,000	.030
2,000	.021	5,000	.034

If the difference between the results from the forward and backward lines between any two bench marks exceeds the allowable error, both the forward and backward lines between the marks must be repeated until an acceptable agreement is obtained. No one of the questioned values is to be used with the new levels to obtain the agreement. Form 258, leveling record—tide station, is to be used for this leveling.

OPERATION OF TIDE STATION

113. The satisfactory functioning of a tide gage depends largely upon the observer in charge, and he should be a person with some knowledge of mechanics and a sufficient scientific training to understand the importance of careful observations.

114. Summary of observer's duties.—Exclusive of work incident to density and temperature observations and the tabulation of records described elsewhere in this volume, the duties of the tide observer at a primary tide station may be summarized as follows, the details of the work being described in separate paragraphs:

Daily.—Inspect tide station, enter comparative time and staff note (pars. 120–126) on tide roll and in form 660 (par. 136), correct gage clocks if necessary (par. 123), readjust pencils for wearing away of lead (par. 128), wind up tension weight, and enter in form 660 any item of interest relating to the station (par. 136).

Semiweekly.—Wind both clocks. Although these are 8-day clocks, semiweekly winding insures against stoppage that might result from an unexpected interruption to the observer's daily visits.

Weekly.—Mail form 660 to office after completing information required on back of form.

Monthly.—Change paper on gage (par. 117), clean pencil screw (par. 131), and forward records to office (pars. 137–139).

Occasionally.—As frequently as necessary clean float well intake (pars. 132–135).

115. Placing paper on gage.—Before placing the paper on the gage a note should be made at the beginning of the roll giving the name of the station, the date, the scale of the gage, the kind of time used, and the name of the person in charge. The supply roller (4, fig. 4) is removed from the gage and passed through the central hole in the blank roll of paper. The roller is then replaced in its supports so that the loose end of the paper will pass from below inward toward the main roller (fig. 10). The tension springs (5, fig. 4) at the sides are moved down so that they will bear against the ends of the roll of paper. These springs may be bent slightly if necessary to hold the roll firmly in place and provide the desired tension in the paper as it is drawn forward.

116. With the main roller disconnected from the motor clock by throwing out of gear the carrier arm (34, fig. 6), the paper is now passed over the main roller and the end inserted in the slot in the receiving roller (17, fig. 5) where it is locked in place by turning the core in the sleeve of the roller. The end of the paper should be cut square before attaching it to the receiving roller and care must be taken to secure it evenly so that the paper will wind up smoothly on the roller. Several turns of the paper are now wound on by turning the roller in a direction such that the paper passes from the main roller over the top of the receiving roller. The main roller is then again connected with the motor clock by throwing the carrier arm into gear with the carrier wheel. Finally, the tension weight is wound up and the paper is ready for the record.

117. Changing paper on gage.—On the first day of each calendar month, or the following day if the first occurs on Sunday, the roll of paper on the gage should be changed. A comparative time and staff note (pars. 120–126) must be entered on the old roll before removal from the gage and another note entered on the new roll immediately after installation. Before removing the old roll, place the tension weight upon some support to remove the strain on the paper and then disconnect the main roller from the motor clock by throwing out of gear the carrier arm (34, fig. 6). A few feet of the paper remaining on the supply roller is wound upon the receiving roller and the paper cut. The receiving roller is then removed from the gage after pressing on the release buttons (18, fig. 5) at the sides. The paper itself is removed from the roller after being released by turning the core inside the shell of the roller. For the installation of a new roll of paper see paragraphs 115–116.

118. Adjusting pencils.—For the original setting of the datum pencil a position near the middle of the paper is in general recommended. After having been once set, any change in its position should be avoided without good cause, but when necessary an explanation should be noted in the record. When securing the datum-pencil holder in place care must be taken to provide sufficient clearance for the passing of the recording-pencil arm, special attention being given to the position of the tripping hook (36, fig. 7) just before the hour, since at that time this hook is at its lowest position. If difficulty is experienced in securing the datum-pencil holder in position by its clamping nut (22, fig. 7), remove this nut together with the datum-

pencil holder and tighten a small screw which is then exposed to view (par. 31), and then reassemble the removed parts.

119. For the original setting of the recording pencil it is the aim to make the adjustment so that as far as practicable extreme tides of occasional occurrence will be recorded. For stations on the open coast this adjustment will bring the curve of the normal tides in the middle portion of the paper, but for stations on rivers the pencil will be adjusted to bring the normal tide curve nearer the low-water side of the paper to leave room above for recording the flood stages of the river. After the original set-up of the instrument changes in adjustment are in general to be avoided as they necessitate certain allowances in the tabulations to preserve a uniform datum. When a change of adjustment is necessary for any reason an explanatory note should be entered in the record.

120. Comparative note.—When an automatic tide gage is originally installed, and daily during its operation, a comparative time and staff note must be entered on the tide roll with the corresponding point on the tide curve clearly indicated (fig. 19). This is absolutely essential in order to obtain the correct time relations and to establish tidal datum planes.

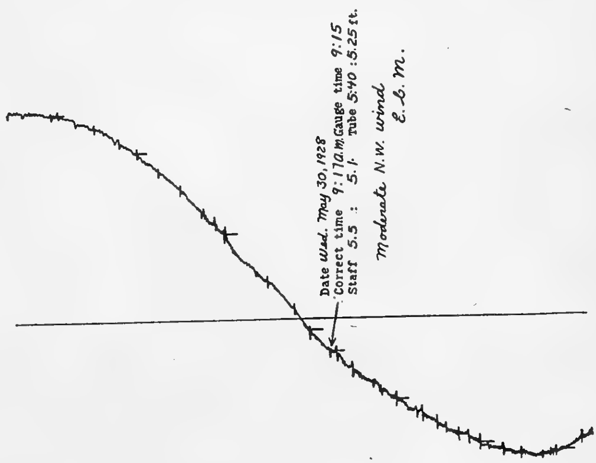

FIGURE 19.—Tide curve and comparative note (standard gage).

121. The comparative note must contain the date, the correct time as obtained from a reliable source, the corresponding time as indicated by the time clock of the tide gage, and the reading taken directly from an outside tide staff or from a nonregistering float gage which may have been installed as a substitute for the tide staff. A statement relative to the wind and weather and the name or initials of the observer making the note should be added. The exact point of the tide curve to which the note applies may be conveniently indicated by first tilting the recording pencil to make a short horizontal line similar to an hour mark and then drawing a tracer from the note to this line. The point may also be indicated by a short vertical line made by rocking the float drum, care being taken to hold the float wire so that it will not spring off the drum.

122. A rubber stamp with suitable inscription is provided for convenience in making the note. In entering the date it is desirable to include the day of the week as a check on the day of the month. Standard time should be used for the record consistently throughout the year regardless of the fact that daylight saving time may have been adopted temporarily for other purposes during certain months.

If desired the times may be expressed according to the 24-hour system in which the hours are numbered consecutively throughout the entire day thus avoiding the necessity of using the designations "a. m." and "p. m." If the usual 12-hour system is used care must be taken to indicate the forenoon and afternoon hours by their customary designations.

123. At the beginning of the record on a tide roll the correct time and the gage time should be in agreement. In subsequent notes the difference between the correct time and the gage time will indicate how much the time clock of the gage has gained or lost since the previous note was entered. *After* each entry has been made the time clock should be set to agree with the correct time. The minute hand of the clock, however, must not be turned backward when between 10 minutes before and 5 minutes after the hour. (See pars. 22–23 for setting and regulating clock.)

124. Reading tide staff.—In taking the tide staff reading, both the highest and lowest points reached by the waves are to be recorded, the two readings being separated by a dash or in some other distinctive manner. If a glass tube is used the height of the water in the tube should also be recorded.

125. The observer will note that the tide staff is graduated in tenths of feet and not inches. The heights in general are to be read to the nearest tenth or half-tenth of a foot, the half-tenth being recorded as 5 in the second decimal place. When the staff is equipped with a glass tube (par. 7) the staff reading corresponding to the water surface inside the tube should be read, but the observer must assure himself that the opening in the bottom of the tube is not clogged, and if there is any wave movement on the outside the water in the tube should show a perceptible oscillation.

126. While individual staff readings may at times seem rough and inaccurate, the final results, depending upon an average of a great number of such readings over a considerable period of time, reach a very satisfactory degree of precision provided they are taken in an unbiased manner. It is of great importance, therefore, that the tide observer when taking staff readings should be uninfluenced by any other consideration, and such readings should be entirely independent of any scale on the automatic tide gage.

127. Adjustment of hour-marking device.—Small variations in the hour-marking device on different instruments preclude detailed instructions applicable to all gages now in use. In all cases, however, care must be taken to avoid any binding between the tripping hook (36, fig. 7) and the tripping rod (26, fig. 7). In the latest type gage the tripping hook must just clear the rod during the first half of each hour. During the last half of the hour the tripping rod gradually recedes from the hook preparatory to striking the hour. When adjustments are necessary, they should, therefore, be made with the minute hand in the first half of the hour.

128. Adjustments may be made at four different points and several trials may be necessary before securing a satisfactory operation of the device. One adjustment consists of changing the position of the recording pencil in its holder, the pencil being secured in place by a binding screw (39, fig. 7). A very slight change in the elevation of the pencil and even a change resulting from the wearing away of

the lead in the pencil may have a sensible effect on the hour-marking device. A second adjustment consists of changing the angle which the recording pencil makes with the paper by means of an adjusting screw (40, fig. 7). A third adjustment changes the angle between the striker weight (29, fig. 8) and the upright supporting the tripping rod. In general this angle will not differ greatly from 90°. The weight is held in position by a binding screw (30, fig. 8), but because of the strain produced by the hourly dropping of the weight there may be a slipping at times. The fourth adjustment relates to the position of the striker lifter (33, fig. 9) attached to a spindle from the time clock. This is secured to the spindle by a binding screw (32, fig. 9) and during the first half of each hour its position should be vertical. During the last half of each hour its position changes through the action of a cam in the clock.

129. Cleaning pencil screw.—One of the most common sources of trouble, which cannot be overemphasized, in the operation of the automatic gage, is the sticking of the pencil arm on the pencil screw. Even when the pencil screw itself appears clean, there may be an accumulation of dirt in the bearing of the pencil arm. Also, while the arm may operate freely in covering the normal range of tide, there may be a sticking as it advances toward either end of the screw for an unusually high or low water. The following operating difficulties frequently have their origin in a sticking pencil screw: (*a*) recording pencil thrown back off the paper on a falling tide, (*b*) curve recorded on falling tide less legible than that of rising tide, (*c*) paper torn by pencil digging in on a rising tide, (*d*) distortion in tide curve, especially a flattening at time of high or low water and steps on a rising or falling tide, (*e*) float wire broken or off drum.

130. The pencil screw should be cleaned at least once each month and at other times when there is any evidence of sticking. The latest type gage is provided with a removable pencil screw which can be taken out of the gage without disturbing any of the wiring. It is released by backing off the capstan bearing pin (45, fig. 9) at the forward end of the screw. The other end of the screw is connected with the drum shaft by a slotted joint. When replacing the pencil screw in the gage, the pencil arm should be placed in the same position as before with allowances for any change in the height of the tide in the meantime. While out of the gage, the pencil screw and the inside of bearing of the pencil arm are to be thoroughly cleaned with kerosene or nonleaded gasoline and any roughness due to corrosion removed by a fine file. The use of emery or crocus cloth is to be avoided. Before replacing the pencil screw in the gage, the movement of the pencil arm along the entire length of the screw as well as the functioning of the return springs at the ends should be checked in the manner described in paragraph 87. Lubricating oil must not be used on the pencil screw or in the bearing of the pencil arm, as the oil tends to collect dust from the atmosphere and when dry forms a sticky film on the metal surfaces. The movement of these parts during the operation of the gage is so slow that the friction between the clean dry metal surfaces is practically negligible.

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131. With the older type gage, a thorough cleaning of the pencil screw cannot be accomplished without disconnecting the wiring, and this is generally undesirable. However, at regular intervals the screw must be wiped clean with a rag moistened with kerosene or nonleaded gasoline, and the best time to do this is when changing the paper after the close of each month. With care to avoid letting the float wire spring off of the drum, the screw may be turned a limited amount to move the pencil arm forward and backward during the cleaning process. A liberal application of kerosene or nonleaded gasoline with a squirt can will be helpful in removing dirt accumulated inside the pencil arm bearing.

132. Clearing float well intake.—Particular care must be taken to keep open the intake to the float well, as even a partial clogging may destroy the value of the record by creating a lag in both time and height of the tide. Clogging may be caused by an accumulation of sediment inside the well, by marine growth at the intake, or by the shoaling of the water in the vicinity. In an iron float well clogging may result from an accumulation of iron rust scales inside the pipe. A clogging of the intake is indicated by a smooth tide curve when the water outside the float well is somewhat rough. Although the float well is designed to dampen down the outside waves, there should always be an unmistakable oscillation of the recording pencil whenever the water is somewhat rough in the vicinity. A smooth, regularly traced curve is to be regarded with suspicion and should occur only when the water outside the float well is smooth.

133. In localities where there is any tendency toward clogging, the observer should establish the practice of clearing the float well at regular intervals. When clearing an iron float well with intake in the center of the standard conical intake coupling, it will generally be necessary first to remove the float from the well and, to avoid any tangling of the float wire when raising the float, the wire should be secured by a clamp or loop around some convenient object to take up the slack. When the intake is not badly clogged it is most conveniently cleared by use of the cleaning tool shown in figure 16. This tool is lowered into the well by a line and is used to tap out any foreign matter which may have collected in the intake.

134. If there is a considerable accumulation of sand in the bottom of the well it may be necessary to use a jointed rod made up of sections of iron pipe which may be fastened together as it is lowered into the well. One-half-inch pipe with outside diameter a little less than ⅞ inch will generally be found satisfactory for the purpose when the diameter of the intake is an inch or more. If the obstruction in the intake is found to be especially difficult to remove, a drill of suitable size soldered in the end of the lowest section of pipe will usually be found effective when other means have failed.

135. For a wooden float well when the intake is in a lower corner of a sloping bottom, the use of the jointed rod without removing the float from the well will probably be found both convenient and effective in ordinary cases. When the intake is in the side of the well rather than the bottom, its clearing will generally be more difficult and necessitate the use of a boat at low tide. When the clogging occurs as a result of the shoaling of the water around the float well, the clearing of the intake becomes a problem which cannot be han-

dled by the usual facilities of the observer and the circumstances must be reported to the office.

136. Weekly report (form 660).—Tide observers are required to forward to the office at the end of each week a report on form 660. The daily notes should correspond to those entered on the marigram itself, but the tube readings may be omitted in this form. If staff readings are taken more than once during the same calendar day, a single set will be sufficient for the weekly report, but all such readings are to be noted on the marigram. In the column of "Remarks" there should be noted such items as "Float well cleaned," "Float wire broken," "Counterpoise wire off drum," "Time clock stopped at 11:15," etc. The operating troubles are to be explained in detail on the back of the form, which must also include all other information requested.

137. Forwarding records to office.—Unless the tide observer tabulates the records, the tide roll is to be forwarded to the office immediately after removal from the gage after the close of each calendar month. If the observer does tabulate the records, the work must be expedited and the records forwarded promptly as possible, as the office has frequent calls for information based upon them. It is expected that the tabulations will be completed and the records forwarded within 1 week after the marigram has been removed from the gage.

138. Before forwarding the tide roll, it should be rewound to bring the record on the inside with the first of the month at the beginning. A label, form 489, is to be filled out as completely as possible, except that at a primary tide station it will be unnecessary to repeat the latitude and longitude each month. The marigrams are numbered consecutively from the beginning of the series regardless of calendar years. The label is to be pasted on the outside of the marigram in such a manner as not to seal the roll. As a protection against tearing, a few inches of the paper at the beginning of the roll should be folded inward, making a smooth edge of double thickness. The label is then pasted parallel to this edge and about 1 inch from it, with the bottom of the label towards the edge.

139. The roll should now be well wrapped for mailing and an addressed franking slip (form 110) pasted on the outside. Two copies of form 413 listing the record must be sent under separate cover. This form is used only for the formal transmission of records, and any matters requiring special attention should be sent as separate communications.

140. Shipment of Government property.—Shipments of instruments or other Government property when too bulky to be sent by mail are sent by express or freight on Government bill of lading. When it is necessary for the tide observer to make any such shipment to the office he will be provided with a bill of lading for the purpose, and no payment of charges, other than drayage which will usually be arranged for in advance, should be made by the tide observer for shipments sent or received by him. Form 412, in duplicate, is used as a transmitting letter when shipping instruments to the office.

141. Requisition for supplies.—A requisition for stationery for use at a tide station may be made by ordinary letter or by a short form requisition letter mimeograph copies of which may be obtained from the Chief, Division of Tides and Currents, upon request. Requisitions

for instruments and general property must be made on form 12. Requisitions for stationery and instruments should always be made on separate forms, as they are handled by different sections of the office.

142. Requisitions for supplies may be made from time to time as needed, but it is recommended that at a primary tide station the quantity of any article requested in a single order be sufficient for a period of about 1 year. The following list is suggestive of the quantity of any article to be included in a single requisition:

Tide rolls for standard tide gage		12
Form 489 (label for tide gage record)		20
Form 660 (weekly report of tide station)		50
Form 457 (density and temperature observations)		25
Form 413 (letter transmitting field records)		50
Form 110 (frank, mailing addressed to Director)		20
Form 12 (requisition for instruments and general property)		10
Requests for stationery (short form)		20
Letter paper for field use, medium	tablet	1
Envelopes addressed to Director, 3⅞ by 8⅞ inches	packages	2
Envelopes, manila, 9½ by 12 inches	package	1
Pencil leads, Scripto, black, BB	do	1
Cheesecloth for cleaning tide gage	yards	3
Tabulation forms (if observer tabulates his marigrams):		
Form 138 (high and low waters)		25
Form 362 (hourly heights)		50
Form 455 (comparative readings)		25

143. **Emergency expenses.**—Tide observers are not expected to incur any expenses in the operation of the tide station unless especially authorized by the Director of the United States Coast and Geodetic Survey. Unless an emergency exists, the tide observer should inform the office of any needed repairs and then wait for instructions. Time will be saved if the tide observer obtains an estimate of the cost of making the needed repairs and submits this when informing the office of the need for the repairs. If the cost is more than nominal, at least three estimates are to be obtained when possible.

144. In case of an emergency in which there would be a considerable loss of record if the observer waited until receiving instructions from the office, he may make immediate arrangements for having the work done, provided the cost is reasonable and does not exceed $5. In such cases arrangements will be made to have payment made directly by the office to the party doing the work, or the observer will be provided with suitable forms for obtaining necessary receipts.

145. When emergency work of considerable magnitude is necessary, the tide observer should inform the office by telegram, which is to be sent collect and not prepaid by the observer.

146. **Furnishing information to public.**—All employees of the United States Coast and Geodetic Survey are expected to be courteous to the public when inquiries are made concerning their work, but the regulations prohibit the furnishing of copies of the records without authority of the Director. When a tide station is so situated that there may be more or less frequent calls by local authorities for data from the tide-gage record, and this is brought to the attention of the office, permission will usually be granted to the tide observer to supply such information upon request, but when this is done the party to whom the information is given should be informed that the results are preliminary and subject to revision by the office.

147. Operating difficulties.—It would be impossible to anticipate all difficulties which might arise in the operation of the automatic tide gage but the principal ones are listed below. The tide observer should become familiar with different parts of his gage by reading the description of the instrument contained in this manual. All the gages in use are not of the same identical pattern but the observer will note any differences which may exist in the gage at his station.

148. Broken or tangled float wire.—Observer visits station and finds float wire off drum, tangled, and perhaps broken. Although this may result from several causes, the most frequent one is a dirty pencil screw which has jammed the gage and prevented the counterpoise from taking up the slack in the float wire as the tide rose. The wiring should be entirely removed from the gage and the pencil screw examined and cleaned in accordance with paragraph 130. New wiring may then be installed as described in paragraphs 91–94. It will not be necessary to attempt to adjust the gage exactly as before, but a note should be entered on the roll itself and also in the weekly report stating that new wiring was installed, and a comparative staff reading must be taken and recorded.

149. Other causes which might lead to a broken or tangled float wire are improper installation of wiring, an obstruction in the path of the counterpoise weight, jamming of a pulley through which one of the wires passes, and an interference between the recording pencil and the datum pencil. If the instructions for attaching counterpoise and float are not strictly followed, it is possible that an excess of wire attached to the float may run off the edge of the float drum at the time of a specially high tide, thus causing a sudden jerk which could break or tangle the wire. An obstruction in the path of the counterpoise weight or the jamming of a pulley through which the wire passes might prevent the weight from functioning and thus permit the slackening of the float wire. A similar effect may be produced if the recording pencil fails to clear the datum pencil in passing because of an improper adjustment of the pencils. See paragraph 118.

150. Clock failure.—If either clock stops frequently or runs persistently fast or slow regardless of all efforts to regulate it by the customary method, a requisition should be made for a new clock unit, and an effort should be made to keep the old clocks functioning while waiting for the new unit. The stopping of either clock may be caused by winding too tight or by a collection of dirt in the works. The latter condition may be temporarily remedied by the use of kerosene. In some of the older types of gages, clock failure may result from a flexure of the frame caused by drawing too tight the screws securing the clock to its case. Any jamming of the supply roll of paper might affect the running of the motor clock, and any unusual resistance in the operation of the hour-marking device would have its effect on the time clock.

151. Failure of hour-marking devices.—Assuming that this is not the result of the stopping of the time clock, any failure will probably be found to be due to an improper adjustment of the device. Instructions given in paragraphs 127–128 should be carefully followed.

152. Torn paper.—If the paper is found torn along the record curve during a rising tide, it is probably the result of a dirty pencil

screw which has forced the pencil arm downward and caused the pencil point to dig into the paper. The softening of the paper by damp weather may be a contributing factor. See paragraphs 129–131 for cleaning pencil screw. An improper adjustment of the hour-marking device whereby the tripping rod presses too tightly against the tripping hook may also result in a tear. A tear along the datum line suggests too great a pressure, too hard a pencil, or a broken pencil point. A tear along the line of prick points at the margin of the paper may result from too heavy a tension weight or too strong a resistance from the tension springs acting upon the supply roll of paper. A torn margin may result from an improper alinement when the tide roll is installed on the gage.

153. Failure to trace curve.—Sometimes sections of the tide curve will be missing without any apparent cause. Assuming the pencil point to be unbroken, if the missing section occurs on a falling tide, it is probably the result of a dirty pencil screw which has lifted the pencil off of the paper temporarily. In some cases the pencil arm may be thrown entirely back away from the paper and remain there until returned to its proper position by the observer. The obvious remedy is the cleaning of the pencil screw in accordance with paragraphs 129–131. If the entire tide curve is very faint, a pencil with softer lead should be used.

154. Distortion of tide curve.—A series of steps in the record or a flattening at the times of high or low water is most frequently caused by a dirty pencil screw and this should be given first attention when the trouble arises. An irregular distortion in the tide curve may also result from the same cause. In very cold weather, a distortion of the curve may be caused by the presence of ice in the float well. Ice collected on the inside wall of the well may impede the movement of the float without stopping it completely, thus causing an irregular movement. See paragraphs 71–72 for precautions against freezing. If ice has already formed in the well a liberal use of salt or hot water is helpful in freeing the float. If an insufficient quantity of kerosene has been placed in the well as a precaution against freezing it is possible for ice to form below the kerosene. See also the following paragraph.

155. Clogged float well.—A clogged float well is evidenced by a consistently smooth tide curve regardless of any roughness in the water outside. As a clogged well causes a lag in the record which greatly impairs its value, it is important that the observer be especially watchful for any indications of this trouble in order that it may be remedied without delay. Unless the surface of the outside water is quite smooth, there should always be a perceptible short period wave oscillation in the record with an amplitude increasing in proportion to the roughness of the outside water. Whenever there is any evidence of the float well being clogged, the observer should follow the instructions in paragraphs 132–135 for clearing the intake. In localities where the clogging occurs frequently, the observer should adopt the practice of clearing the intake at regular intervals.

INSPECTION OF TIDE STATION

156. In making an inspection of a primary tide station note should be made of the following matters and a report of the conditions found forwarded to the office in form 681, report—tide station. Informa-

tion relating to the station supplied by the office should be verified by the inspector as far as practicable.

157. Location.—If changed conditions in the vicinity of a tide station make it desirable that the location be changed, the inspector should ascertain whether there is a more suitable site and report accordingly with his recommendations.

158. Tide staff.—A careful inspection should be made of the tide staff, the legibility of its scale, and to see whether it is firmly secured in a vertical position. If a portable tide staff is in use, the staff support should be examined to see that it is substantially secured and that the metal plate at the top is firmly fastened in place. The metal stop on the back of the portable staff must be checked in regard to its position relative to the tide staff scale (see par. 111) and to see that it is firmly secured. The staff should be lowered into its support to see whether any obstructions exist to prevent the stop on the staff from resting flatly upon the metal plate at the top of the support.

159. The tide observer should be questioned in regard to any changes in the position of the tide staff of which he may have knowledge, and should be advised to always report immediately to the office any occurrence that might affect the elevation of the tide staff. If a tide staff has been accidentally knocked out of place or loosened and afterward resecured by the observer, it is important that the office have a record of the date on which this occurred.

160. Tape gage.—If there is a tape gage or other substitute for a tide staff at the station, this should be described and any known changes since the previous inspection reported. For a tape gage, the relation of the plane of flotation to the tape scale should be checked by the method described in paragraphs 82 to 86. If there is a tide staff in addition to some other form of nonregistering tide gage at the station, some simultaneous readings from both gages should be taken, preferably when the water is reasonably calm, but if the water is rough the amplitude should be noted as an indication of the reliability of the comparison.

161. Automatic tide gage.—The automatic tide gage is to be examined to ascertain if it is operating satisfactorily, special attention being given to the clocks, the hour-marking device, the pencil screw, and the wiring, which have been described in detail in the preceding pages. Note whether the gage is so placed over the float well that the float clears the sides of the well without scraping. Inquiry should be made as to whether the observer has experienced any of the operating difficulties listed in paragraphs 147 to 155, and such adjustments should be made and advice given as necessary.

162. Float well.—Note the general condition of the float well and whether it is securely fastened in place. Special attention must be given to the intake to the well and a rod or cleaning tool should be passed through the opening. (See paragraphs 132–135.) If there is a separate well for a tape gage, this must be given the same attention as the one for the automatic gage.

163. Observations.—The methods and procedure used by the observer in attending to his duties are to be noted and his attention called to any matter requiring change. Any unusual method or procedure should be noted in the report. The inspecting officer should make an independent reading of the tide staff and enter it on the tide

record in accordance with instructions for comparative note in paragraphs 120–126.

164. Measurements.—The depth of the harbor bottom at the tide staff and at the float well as referred to the floor of the wharf or other specified fixed point should be taken and reported at each inspection in order that there may be a record of any change in the depth which may occur from time to time. These depths need be given only to the nearest foot or half-foot. Previous measurements of the relation of the tide staff and float well to the wharf floor should also be verified.

165. Bench marks.—At the time of inspection search should be made for all bench marks within a radius of 1 mile from the tide station, their condition noted, and the old description revised if necessary. (See par. 109.) If an old bench mark cannot be found, a statement to that effect should be included in the record, together with an explanation whether the failure to find the mark results from an inadequate description, inaccessibility of location, or positive information of its destruction. If the number of bench marks recovered is less than the minimum of five marks for a primary tide station, the inspecting officer should arrange for the establishment of such additional marks as may be necessary. Descriptions and reports concerning bench marks are to be included in the leveling record, form 258.

166. Leveling.—On the occasion of each inspection the tide staff must be connected by a double line of levels with *not less than three substantial* bench marks including the primary bench mark, and the results must come within the limits of accuracy indicated in paragraph 112. For procedure in regard to leveling to a portable tide staff or to a tape gage, see paragraph 111. The height of a bench mark above the datum of a tape gage of the type illustrated by figure 2 is equal to the height of the bench mark above the reading mark of the gage plus the reading of the plane of flotation on the tape scale extended. If the bench mark is below the reading mark, the difference in elevation is subtracted from the reading of the plane of flotation. Form 258 is to be used for the leveling record.

167. Recommendations.—A report of inspection should include recommendations for such repairs or changes as may appear desirable, with an estimate of the cost when possible. When repairs are urgently required, the inspecting officer should give them immediate attention, requesting by telegraph approval for expenditure of such extra funds as may be needed.

SECONDARY TIDE STATION

168. Secondary tide stations include those which are operated over a very limited period of time, the observations in general extend over less than a year but in some cases covering more than a year. Secondary tide stations are established for the purpose of obtaining general tidal information for a locality and also to obtain specific data for the reduction of soundings in connection with the hydrographic surveys. Observations at a secondary tide station are not usually sufficient for a precise independent determination of tidal planes, but when reduced by comparison with simultaneous observations at a suitable primary tide station very satisfactory results may be obtained.

LOCATION

169. The selection of a location for a secondary tide station will depend upon the purpose for which it is to be established. For the hydrographic survey of any area there should be a principal station somewhat centrally located which will be maintained through the time the survey is in progress. If available, a standard automatic tide gage should be installed at the principal station. If there is already a primary tide station located within the area to be surveyed this may serve as the principal station.

170. Gages are to be established at other points in the immediate vicinity of the soundings as the work progresses, the distribution depending upon the change in the tide from point to point. In some localities the tide may occur practically simultaneously with nearly equal range over a large area. In such a case a single tide station will serve for the entire area. In other localities the tide may change rapidly in passing from one point to another and it may be necessary to establish gages at close intervals. For the subsidiary stations, the portable automatic tide gage will generally be found most convenient to install and the records sufficiently accurate for the purpose. For a very short series of observations, a plain tide staff to be read at certain fixed intervals may be found sufficient.

171. For sounding on outer coast.—For use in reduction of soundings on offshore sounding work the tide record from a gage located in a harbor, such as at a primary tide station, can be used with corrections applied for difference in time and height. It is advisable, however, to avoid a location well inside a river mouth or shallow estuary or in a body of water having a narrow connection with the sea. For use in connection with inshore hydrography along the outer coast subsidiary staffs or portable gages should be established where possible in the immediate vicinity of the work and connected by means of comparison of simultaneous observations with nearby stations where long series have been obtained, if available.

172. Exposed channel approaches.—For surveys of exposed channel approaches, where the depths are near the draft of vessels and where especially accurate soundings will therefore be required, for the reduction of which the record from an inshore tide staff is not sufficiently accurate, a temporary station should be established by pumping down a pile or stake and several hours' tide observations obtained on a portable gage or fixed staff simultaneous with the inshore station. The observations at the temporary station should cover at least a high and a low water.

173. Abnormal tides due to configuration of shore.—In straits connecting two bodies of water having tides of different ranges and epochs of occurrence it usually happens that in portions of the straits the tide varies rapidly from place to place. Hell Gate, East River, N. Y., and the channel north of Vancouver Island, British Columbia, are examples. When sounding in such straits, tide stations should be established at frequent intervals. At times also appreciable differences both in time and height of tide occur on the different sides of the same island in an archipelago.

174. Upper reaches of tidal rivers.—In the narrow upper reaches of tidal rivers a tide station is not representative of any considerable area, and stations should be spaced sufficiently close together that

sounding will not be done at a considerable distance from a tide station.

175. Effect of wind.—In large bays of comparatively shallow depth and with small range of tide, and in broad stretches of rivers or along shores where the water is shoal, the wind has considerable effect on the time and height of the tide. In such places under unfavorable weather conditions the state of the tide at moderate distances from a tide gage may be quite different from that at the gage, particularly if differently exposed to the wind direction. Sounding at some distance from a tide gage under such conditions will result in failure of sounding lines to cross, at times by several feet.

176. Where such conditions prevail, a tide staff or portable gage should be established in the immediate vicinity of the work for the reduction of soundings and connected with the central or control gage by simultaneous observations made during normal weather conditions. If a portable gage is established at the auxiliary station, 2 or 3 days of simultaneous observations should be obtained. If a plain staff is established at the auxiliary station, the observations for connecting with the central gage need cover only those hours during which sounding dependent upon the auxiliary gage is being done, except that several high and several low waters should be included, preferably a complete range of tide on each day that the staff is used.

177. When surveying shallow bodies of water, such as the sounds of North Carolina, where the range of tide is small and fluctuations due to meterological conditions considerable, it will be necessary to confine the sounding work of any day during periods of heavy winds to an area in the vicinity of a tide gage or, if sounding on long lines, to have sufficient auxiliary tide stations in actual operation scattered over the area to furnish correct reducers for the soundings at different positions along the sounding lines.

ESTABLISHMENT OF SECONDARY TIDE STATION

178. Certain precautions which are required when establishing a primary tide station because of its more or less permanent character are unnecessary when installing a secondary tide station. Without sacrificing anything which might impair the reliability of the record, the installation of a tide station to be occupied for only a short period of time may be somewhat simplified.

179. The tide staff may be a plain board with graduated scale nailed to a convenient support. The staff must, however, be connected with a system of bench marks as described in paragraphs 97–112. The smaller and more conveniently installed portable automatic tide gage may usually be substituted for the larger standard gage. The float well may be a simple construction of plain boards; or, if the portable automatic gage is used, made up of convenient lengths of standard 4-inch iron pipe. If the observations are taken during the summer time only, no tide house is necessary, a waterproof box affording sufficient shelter for the standard gage, and the iron cover provided with the portable gage serving as ample protection for the latter. In the winter time a tide house is more or less necessary

as a protection against the elements when changing the record on the gage.

180. In selecting the site for a secondary tide station existing facilities and the accessibility of the location to an observer must generally be taken into account. For the standard tide gage a convenient wharf is especially desired. Otherwise some special platform must be constructed. The portable gage, partially supported by its own 4-inch iron pipe float well, may be secured to a single pile, to a fish-net stake, or against a cliff (figs. 20–21). Care should be taken to install the gage at a point where the depth is sufficient to operate the gage at low tide.

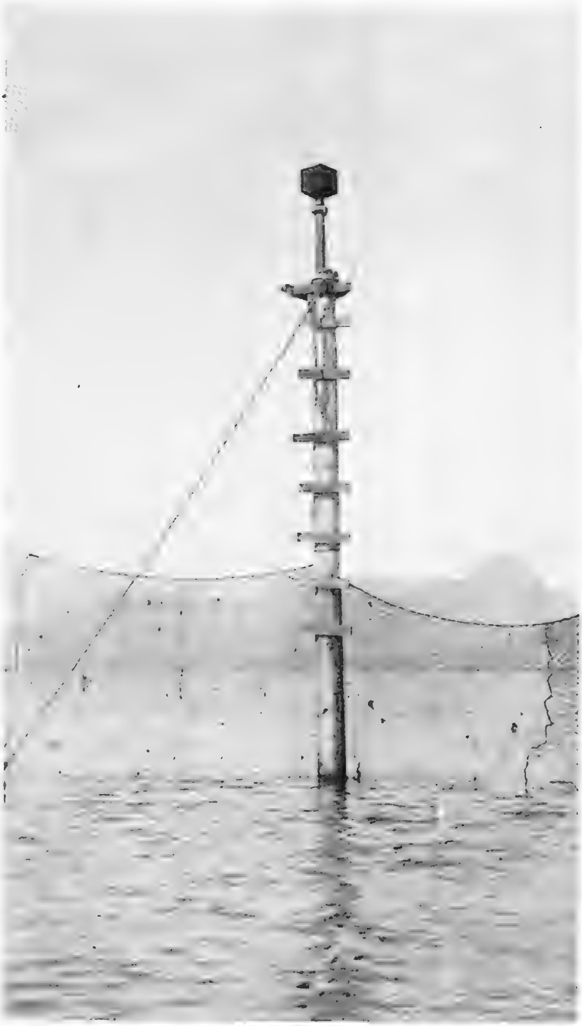


FIGURE 20.—Installation portable automatic tide gage on fish trap stake.

181. The installation of the standard automatic tide gage has already been described on pages 32–37 and its operation discussed on pages 41–50. However, all the instructions given for the guidance of the tide observer at a primary tide station will not necessarily be applicable to a tide observer at a secondary tide station, who is working under the direction of the chief of party. The installation and operation of the portable automatic tide gage are described on the following pages.

INSTALLATION AND OPERATION OF PORTABLE AUTOMATIC TIDE GAGE

182. Since the portable tide gage is designed to be set with stylus reading in agreement with the reading on the tide staff, the latter when installed should be so placed that its graduation corresponding to the middle of the height scale of the record paper shall be at approximate

half-tide level or midway between the extreme tides to be expected during the period of observations. With such a setting the curve traced by the portable gage will be approximately centered on the record paper.

183. Float well.—The base of the portable automatic tide gage is provided with a sleeve to fit on the top of a float well. In the later gages this provides directly for a 4-inch float pipe, but in the earlier gages it provided only for a 3½-inch pipe and a reducing coupling is necessary to adapt it to the larger pipe. The pipe in addition to serving as a float well acts also as a support for the instrument. When the gage is installed on a wharf a flange coupling with a short section of pipe above the deck affords a ready means of supporting the float pipe. The conical inlet coupling is screwed on the bottom of the longer section, reaching below extreme low water. To provide a support for the instrument in a location at which no wharf or platform is available, an additional section of pipe is screwed into this conical inlet coupling on its bottom end and perforated with several large holes to allow free access of the water to the inlet in the coupling. (These holes should be as large as can be conveniently made, so as not to become clogged.) This lower section rests on the bottom, and the float pipe may be lashed to a single pile or net stake or lashed securely against an overhanging cliff where depth of water permits (figs. 20 and 21). In localities where little penetration can be obtained for a single

FIGURE 21.—Installation portable automatic tide gage against rocky cliff.

stake three sharpened poles of suitable length may be driven about 6 or 8 feet apart and the upper ends brought together and lashed in the form of a tripod, the float pipe being lashed in a vertical position to the apex of the tripod.

184. Attaching float.—When installing the instrument on the float pipe the first step is the attaching of the float. The length of wire required may be determined as follows:

Let A=distance in feet of float drum to water surface. (Actual measurement not necessary.)

Let B=height in feet of tide above or below approximate mean tide level.

In the formula below use plus (+) B if tide at the time is above mean tide level and minus (−) B if below mean tide level.

Length of wire required$=A+15$ feet$\pm B$.

Take a spool of wire and attach one end of the wire to the float and lower it into the well. Allowing a few inches for the distance from the top of the well to the float-wire drum, measure off an additional length equal to 15 feet$\pm B$, the value of B being estimated from the stage of the tide, and then cut the wire. Pass the loose end of the wire over the fixed fair leader and through the opening in the base of the instrument, and then before attaching the wire to the drum wind up the spring either by turning the drum counterclockwise, as viewed from the side shown in figure 13, or by use of the clock key on the drum axle (30, fig. 13). The spring should be wound up completely and then slackened off about four turns. Holding the drum in this position, the float wire is now passed through the small drill hole near the edge of the drum and knotted. The drum should now be permitted to turn slowly through the action of the spring, winding up the float wire, care being taken that the wire follows the threads in the face of the drum. When all the slack in the wire has been taken up the gage is placed in position on top of the float pipe and locked by means of the two anchor hooks (27, fig. 13).

185. Counterpoise spring.—If the float wire has been cut off at the proper length and the instructions described in the preceding paragraph followed the counterpoise spring will be wound to the proper tension; but if further adjustment to the tension is necessary this may be made by using the clock key on the subsidiary axle (30, fig. 13) of the float drum.

186. Gear train.—Having determined the scale of the record to be employed from a knowledge of the approximate range of tide at the station, the proper gears for the float-drum axle and the stylus screw corresponding to that scale are given in the table on page 23. The gears to be used are also printed on the cross-section record paper for each scale. The number of teeth is stamped in each gear and care must be taken in selecting and installing the correct gears corresponding to the scale used.

187. Although the same idle gear (8, fig. 11) is used for all scales, its position varies with the different gear combinations. When changing the gears the idler must be removed, and after the other gears have been installed, it is replaced, being secured by the gear screw (9, fig. 11) in the particular hole provided for the combination. The lever nut (10, fig. 11) provides a convenient means for loosening or tightening the gear screw securing the idle gear. The gears attached

to the stylus screw and the float-drum axle are easily removed after taking off the nuts (7, 12, fig. 11) holding them in place.

188. Record cylinder.—The record cylinder with the clock movement inside is now installed in its supports. The clockwork rotates the cylinder in such a direction that its top moves toward the stylus screw, and when installing the cylinder it should be placed in its supports with the capstan nut (4, fig. 11) on the same side of the instrument as the train of gear wheels, this being designated as the front of the gage.

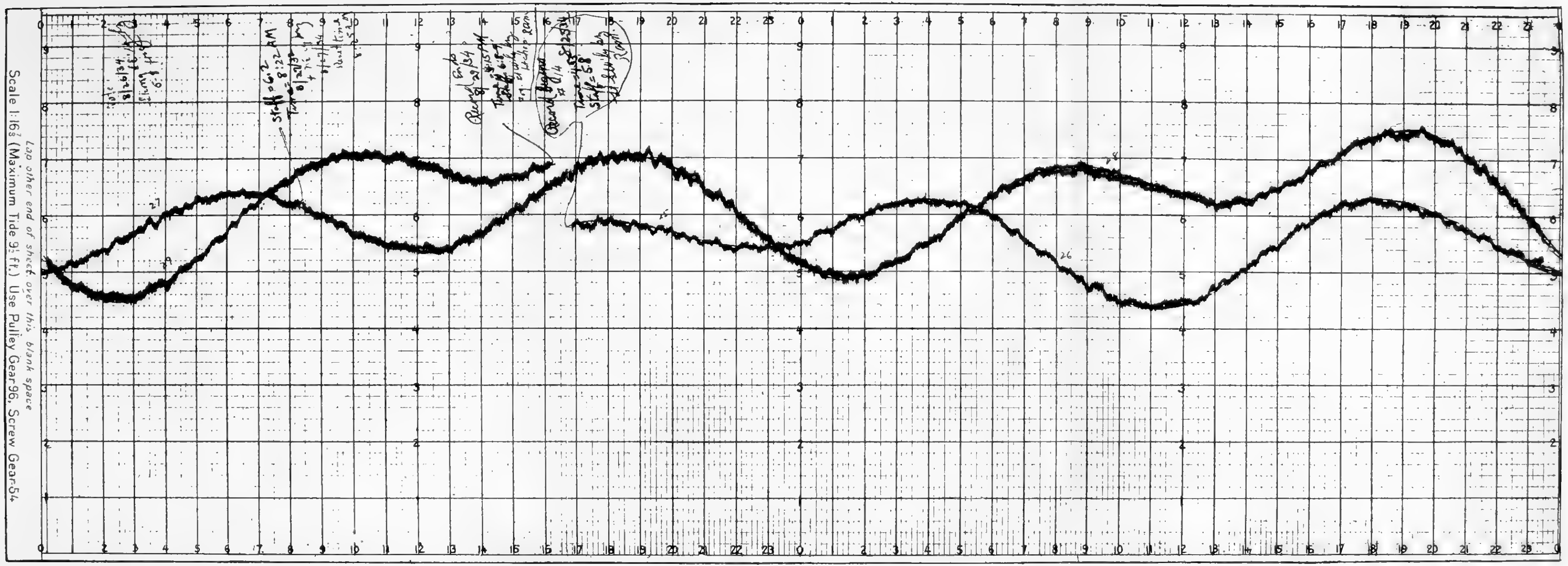
189. Record paper.—Five different scales of record paper are provided and care must be taken to select the scale desired and to see that the gears printed on the sheet are the same as the corresponding gears on the gage. With the capstan nut (4, fig. 11) loosened, the paper is placed on the cylinder with the zero of the height scale toward the front of the instrument; that is, at the same end of the cylinder as the capstan nut. The paper is held in place by a metal clip (24, fig. 12), this clip being released at one end when installing the paper. After the paper is in place, the cylinder is turned until the stylus reading on the paper scale corresponds approximately to the correct time and the nut at the end is then tightened to secure the cylinder in this position.

190. Two days of record are traced on the sheet of paper for each revolution of the cylinder. Since the times of high and low water occur about 50 minutes later each day, the tide curve traced on the same sheet during several revolutions of the cylinder separates sufficiently to be distinctive unless the range of tide is very small. Although a singe sheet of record paper might serve for an entire week, it is recommended that a new sheet be placed on the gage every 3 or 4 days.

191. Setting stylus.—To set the stylus to the approximate height of the tide as read on the tide staff, the nut (7, fig. 11) holding the upper gear to the stylus screw is unclamped, and the stylus screw may then be turned freely to bring the stylus to the reading desired. The gear is then again clamped in position. A finer adjustment for height may now be obtained by means of the slow-motion screw (25, fig. 12) provided for the purpose. The stylus should be reset to agree with the staff reading each time the record paper is renewed.

192. While the approximate time setting of the stylus is obtained by the turning of the record cylinder as described in paragraph 189, a finer adjustment is secured by means of the slow-motion screw (34, fig. 13). When setting the stylus for time, whatever slack there may be in the record cylinder due to lost motion in the gears should first be taken out by lightly placing the hand on top of the cylinder and drawing it in a direction away from the stylus.

193. Care of clock.—Although the clock enclosed in the record cylinder has an 8-day movement, it is recommended that it be wound semiweekly. The clock is regulated by means of the small end of the clock key inserted in the small keyhole in the front end of the cylinder. When regulating the clock, however, the record cylinder should be allowed a full 48-hour revolution and the clock movement adjusted according to the amount that it fails or overruns a complete revolution of the cylinder and not for any particular hour on the cross-section paper.



735445 O - 47 (Face p. 59)

FIGURE 22.—Tide curve and comparative notes (portable gage).

194. Cleaning stylus screw.—For the efficient functioning of the gage it is important that the stylus screw be cleaned at frequent intervals. This should be done in the same manner as with the pencil screw of the standard gage. (See pars. 129–131.)

195. Cleaning float pipe.—If the gage is to be operated for a considerable period of time the float pipe should be cleaned occasionally to prevent the opening in the conical inlet coupling becoming clogged, It should be cleaned by removing the float from the pipe, inserting the cleaning tool to which a line has been attached, and raising and lowering it several times in the pipe. (See pars. 132–134.)

196. Comparative note.—Each day the tide gage is visited, a comparative note giving the date, the correct time, and staff reading should be entered on the marigram (fig. 22). The stylus is to be adjusted when necessary to agree with the correct time and staff reading. As unbiased staff readings are necessary for the proper reference of the various tide planes to bench marks, care must be taken by the observer to avoid being influenced by a previous setting of the stylus on the cross-section paper when taking a new staff reading. However, when an unusual rough state of the water renders a staff reading somewhat unreliable, a previous setting of the stylus under more favorable conditions should be retained without change.

197. To indicate on the tide curve the exact point to which the comparative note refers, first rock the stylus holder (35, fig. 13) slightly to make a short line parallel to the edge of the paper. Next place the hand lightly on the float drum (17, fig. 12) and raise the float a little way out of the water and then lower it, making a short vertical line on the marigram. The point indicated by the intersection of these lines is then connected with the comparative note by a light line.

FIELD REDUCTIONS

198. Preliminary computations of tidal data to obtain tide reducers for soundings are often carried on in the field. The processes are covered in the following chapter on Tabulation and Reduction, but for field purposes, parts of the instructions not directly applicable to the work in hand may be omitted. Unless there is special need to expedite the reductions in the field the planes of reference for the reduction of soundings will be furnished by the office upon the receipt of the original tide and leveling record.

TABULATION AND REDUCTION

PRELIMINARY WORK

199. The original tide records to be tabulated will vary in form according to the kind of tide gage used in taking the observations. The records generally consist of tide rolls from the standard automatic tide gage or tide sheets from the portable automatic tide gage. The following general instructions are applicable to the several forms used for the tabulations and reductions. The work is to be done neatly and in ink. Interpolated or inferred values are to be indicated by the use of brackets. The heading on each sheet will in general be filled out as completely as possible in order that it may be fully identified, but when a tabulation covers several sheets a repetition of the latitude

and longitude of the place is unnecessary, and for a continuing series the spaces for the beginning and ending of the observations may be left blank. The height datum in the heading refers to the datum actually used for the tabulation, which is generally the tide staff zero. Standard time is to be used consistently throughout the year regardless of the fact that daylight-saving time may have been temporarily adopted in some localities. The hours of the day are to be numbered consecutively from 0^h (midnight) to 23^h (11 p. m.) to avoid the necessity of using the terms "a. m." and "p. m."

200. Checking time.—In the portable gage record, the hours are indicated by the numbered vertical lines of the cross-section paper, the hours being subdivided into 10-minute spaces by finer vertical lines. The time as indicated by these vertical lines is to be compared with the correct time as given in the comparative notes entered by the observer. Assuming that the observer has corrected any clock error at each visit to the tide station, any loss or gain may be prorated over the period intervening between the visits unless there is evidence to indicate that the loss or gain was not uniform.

201. In the standard gage record the hours are indicated by short horizontal lines made automatically by the time clock of the gage. The hour begins at the instant the mark leaves the curve, the length of the stroke having no significance. The time notes entered on the record by the observer should be examined, and if it is found that the difference between the correct time and the gage time does not exceed 3 minutes at any time, the hour marks as automatically made by the gage may be accepted as correct and marked accordingly. In cases where the hour marks are appreciably in error due to failure of the time clock to keep correct time, the total error indicated by the time clock may be prorated among the hour marks effected on the assumption that the time clock has lost or gained uniformly between consecutive comparative notes. The marks are to be numbered consecutively from 0 (midnight) to 23 (11 p. m.), and the numbering checked at each time note on the marigram. In order to expedite the work, the numbering of the odd hours may be omitted if desired. The beginning of each day at the 0 hour should be marked with the appropriate date.

202. In cases where the hour-marking device has failed to work the following method may be used: First, from the comparative time notes ascertain the position on the curve of the nearest exact hour for each note made during the period when the hour-marking device was not functioning. This is done by laying off 1 inch on a piece of paper and dividing it into 12 equal parts, the inch measured parallel to the datum line representing 1 hour on the tide curve and each of the divisions 5 minutes. The correct time of the point on the curve being known, as indicated by a time note, the nearest exact hour is laid off by means of this "time scale." Second, through the points thus found, indicating the exact hours, draw lines perpendicular to the datum line and extending across the paper. Third, prepare a "dividing scale" from a strip of paper somewhat longer than the greatest distance between the time notes on the marigram. On the edge lay off equal divisions about 1$\frac{1}{32}$ inches long. These divisions should be numbered consecutively from 0^h to 23^h and repeated if necessary. This scale is then adjusted obliquely between two consecutive cross lines passing through the correct hour points so that the numbers on the scale will

agree with the hours represented by the cross lines. With the scale in this position, each division is marked on the marigram by a dot. Fourth, these hour dots are referred to the tide curve by lines drawn through the dots and perpendicular to the datum line. These hour lines are numbered in the same manner as the hour marks automatically made by the time clock.

203. Checking height datum.—In the portable gage record, the heights are indicated by the horizontal ruling of the profile paper, the zero of which is assumed to correspond to the tide staff zero unless otherwise stated. The height as indicated by the horizontal ruling is to be compared with the actual staff reading as recorded in the comparative notes and allowance made for any difference when tabulating the record. The portable gage is designed to be reset whenever necessary to keep the scale and staff readings in agreement.

204. The determination of the height datum for the standard gage record is radically different from the method used for the portable gage. In the standard gage, no attempt is made to establish in advance any particular relation between gage and staff datum. The aim is to keep the gage datum uniform throughout the entire month, and then, after the record has been removed from the gage, to determine the relation of its datum to the staff zero by the average of the daily comparisons covering the entire month. A special form is provided for the computation and its use is described in the following paragraphs.

205. Comparative readings (form 455).—This form (fig. 23) is used to obtain the relation between the datum line of a standard automatic tide-gage record and the datum adopted for the tabulations. The latter datum is either the zero of the tide staff or tape gage in actual use, or has a definite relation to the same. At primary tide stations it is the aim to maintain a fixed datum for the tabulations throughout the entire series of observations, and constants are introduced to take account of any changes in the elevation of the tide staff. The corrected setting as calculated in form 455 represents the scale reading of the datum line as referred to the datum adopted for the tabulations. A movable scale, usually of glass, is used in making these tabulations. In using this scale the side on which the graduations are cut should always be kept down next to the paper to avoid errors due to parallax in reading. The numbering of the divisions may be written on the upper surface.

206. In the first three columns of form 455, the tabulator notes, respectively, the date, the time of staff reading, and the water level as read on the staff or tape, these items being taken directly from the observers notes on the tide roll. The staff reading entered in the form is the mean between the highest and lowest readings recorded, but if a glass tube is used on the staff, the reading entered in the form should be the mean of the tube readings. If a tape gage is used, the word "staff" at the head of the third column may be changed to "tape" and the reading entered should be the mean of the highest and lowest tape readings.

207. The preliminary scale setting of datum line, to be entered in the heading of the form, may be arbitrarily chosen at any convenient value. This preliminary setting should preferably be of such a value

735445 O - 47 - 5

that the scale readings from the tide curve will be from ½ to 1½ feet less than the corresponding staff readings. The scale reading selected

Form 455
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Ed. July, 1928

TIDES: COMPARATIVE READINGS

Station: Seattle, Washington Lat. 47° 37′
Party of W. C. Meyer Time meridian 120° W. Long. 122° 20′
Obs. begin Obs. end Tabulated by C. D. A. Date Feb. 14, 1928.
Tide Gauge No. 96 Scale 1:24 Preliminary scale setting of datum line 16.00 feet.

DATE Year 1928 mo.	d.	TIME OF STAFF READING h.	m.	STAFF A feet	SCALE B feet	DIFFERENCE A−B feet	PHASE OF TIDE*	REMARKS	
Jan	3	14	00	18.90	18.30	0.60	F	Scale setting for Jan. 3 to Jan. 5	
	4	14	00	19.25	18.60	0.65	H	Sum of differences	1.95
	5	14	00	19.60	18.90	0.70	H	Mean difference	0.65
								Preliminary setting	16.00
	5	15	16	19.20	23.00	−3.80	F	Setting for reduction	
	6	13	55	18.45	22.30	−3.85	R	to tide staff	16.65
	7	14	58	18.55	22.30	−3.75	R	Constant for fixed datum	−0.03
	8	16	29	18.65	22.60	−3.95	H	Setting for reduction	
	9	13	58	15.60	19.20	−3.60	R	to fixed datum	16.62
	10	14	58	14.85	18.60	−3.75	R		
	11	16	00	14.20	17.90	−3.70	R		
	12	11	00	18.55	22.40	−3.85	F	New float wire installed	
	13	9	59	20.10	24.00	−3.90	H	on Jan 5th	
	14	10	58	19.15	23.00	−3.85	F		
	16	11	30	17.90	21.75	−3.85	H		
	17	13	00	17.10	21.00	−3.90	F		
	18	13	00	17.25	21.10	−3.85	H		
	19	13	58	17.25	21.10	−3.85	H		
	20	14	00	17.55	21.50	−3.95	H		
	21	15	00	18.25	22.20	−3.95	H		
	23	15	02	17.45	21.20	−3.75	R		
	24	15	59	17.35	21.25	−3.90	R		
	25	15	58	16.00	19.80	−3.80	R		
	26	10	58	16.05	20.00	−3.95	F	Scale setting for Jan. 5 to Feb. 1	
	27	10	00	18.45	22.35	−3.90	F	Sum of differences	−96.25
	28	11	00	18.25	22.30	−4.05	F	Mean difference	−3.85
	30	11	41	18.90	22.85	−3.95	F	Preliminary setting	16.00
	31	11	00	19.00	22.80	−3.80	H	Setting for reduction to tide staff	12.15
Feb	1	12	01	18.80	22.60	−3.80	H	Constant for fixed datum	−0.03
								Setting for reduction to fixed datum	12.12

* In the column headed "Phase of Tide" write the appropriate one of the four following symbols: H, for high water; L, for low water; R, for rising tide; and F, for falling tide. Use Form 138 for tabulating high and low water.

FIGURE 23.—Form 455, comparative readings.

for the comparison should be ruled across the glass scale on the underside.

208. The values in the fourth column of the form are obtained by placing the scale on the record with the preliminary setting in coincidence with the datum line and reading the height of the curve at the point to which the corresponding staff reading refers. These readings are to be taken to the nearest 0.05 foot. The difference between staff and scale reading is to be entered in the fifth column,

and the phase of the tide at the time the staff reading was taken in the next column. Any change in the adjustment of the gage should be explained in the column of "remarks."

209. If there has been no change in the adjustment of the gage, the differences (A−B) should be approximately equal. If an individual value differs materially from the apparent average of all, it must be rejected and excluded from the computation of the mean. The rejection is indicated by encircling the value in question. The differences are now summed and a mean obtained, the result being carried to two decimal places. To this mean difference there is added the preliminary scale setting and also any constant that may be necessary to refer to any datum other than staff zero. When a constant is necessary it is furnished by the office. The algebraic sum of these quantities will give the corrected scale setting to be used in the tabulations of the hourly heights and the high and low waters.

210. If there has been any change in the adjustment of the gage, such as would be caused by replacing a broken float wire, the introduction of kerosene in the float well, a change in the position of the datum line, etc., the differences will form distinct groups. In such cases separate means and corrected scale settings must be computed for each adjustment of the gage.

211. Sometimes an extreme high or low tide may move the pencil arm to the extreme limit of its motion so that it becomes disengaged from the threaded portion of the pencil screw. If the change in the height of the tide beyond this limit is small, the pencil arm will automatically reengage the screw thread after the tide reverses without any change in the adjustment of the gage, but if the tide continues to rise or fall after the disengagement of the pencil arm by an amount equal to or greater than the circumference of the float-wire drum, the adjustment of the gage will be automatically changed. Each complete turn of the drum at such times will be found registered by a jog in the record near the edge of the paper, and each such turn will signify a change in the adjustment equal to the circumference of the float drum in use. If such change takes place at the time of high water, the curve will be lowered and the scale readings diminished, but if it takes place at the time of low water, the curve will be raised and the scale readings increased.

212. In using form 455 the tide roll should be taken as the unit, regardless of the beginning or end of the calendar month, and each comparative note made by the observer on the tide roll should be included in the form.

HIGH AND LOW WATER TABULATION

213. Form 138 (figs. 24, 25) is designed for the tabulation of high and low waters, but for a very short series the high and low waters may be tabulated directly in form 248 for the comparison of simultaneous observations (fig. 27). When form 138 is used the tabulations will in general be arranged by calendar months, but if the entire series of observations does not exceed 31 days the tabulations may be included on a single sheet of the form. Tide observers who tabulate their own records should, after completing the tabulations for any calendar month, retain a memorandum of any high and low waters at

the end of the tide roll which pertain to the following month in order that they may be included in the tabulations for that month.

214. Times.—The times of the high and low waters are to be ex-

Form 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Ed. Feb., 1928

TIDES: HIGH AND LOW WATERS

Station: *Seattle, Washington* Lat. *47°37'*

Observations begin ______ end ______ Long. *122°20'*

Time meridian *120° W* Height datum *T.S. zero (1904)* which is *29.56* ft. below B. M. *7*

11—671

DATE Year 1928	Moon's Transits (Greenwich mean civil)	Time of— High Water	Time of— Low Water	Lunitidal Interval High Water	Lunitidal Interval Low Water	Height of— High Water	Height of— Low Water	REMARKS
mo. d.	hr. dec. 18.3	hr. dec.	hr. dec.	hr. dec.	hr. dec.	feet	feet	
Jan. 1	(6.7)	11.4	4.5	(4.7)	10.2	20.2	11.6	
	19.1	—	18.4	—	(11.7)	—	9.5	
2	(7.5)	0.9	5.8	5.8	10.7	15.7	13.1	
	20.0	12.0	19.1	(4.5)	(11.6)	19.8	7.7	
3	(8.4)	2.4	7.0	6.4	11.0	17.0	14.6	
	20.9	12.9	20.0	(4.5)	(11.6)	19.6	6.7	
4	(9.4)	3.5	8.2	6.6	11.3	17.9	15.0	
	21.8	13.8	20.9	(4.4)	(11.5)	19.2	5.8	
5	(10.3)	4.3	9.3	6.5	11.5	19.2	15.6	
	22.8	14.5	21.7	(4.2)	(11.4)	19.5	5.0	
6	(11.4)	5.2	10.4	6.4	11.6	19.7	15.6	
	23.9	15.3	22.4	(3.9)	(11.0)	19.0	4.1	
7	—	6.0	11.1	6.1	11.2	19.8	15.1	
	(12.4)	16.0	23.0	(3.6)	(10.6)	18.9	4.3	
8	0.9	6.7	12.0	5.8	11.1	19.9	15.0	
	(13.3)	17.0	23.9	(3.7)	(10.6)	18.8	4.9	
9	1.8	7.3	—	5.5	—	20.1	—	
	(14.2)	17.8	13.0	(3.6)	11.2	18.4	14.8	
10	2.7	8.0	0.5	5.3	(10.3)	20.0	5.5	
	(15.1)	18.5	14.0	(3.4)	11.3	17.3	14.2	
11	3.5	8.3	1.0	4.8	(9.9)	19.9	6.5	
	(15.8)	19.7	15.0	(3.9)	11.5	16.6	13.5	
12	4.2	9.1	1.9	4.9	(10.1)	19.8	8.1	
	(16.6)	20.5	15.7	(3.9)	11.5	16.0	13.1	
13	4.9	9.7	2.6	4.8	(10.0)	20.2	9.8	
	(17.3)	21.8	16.7	(4.5)	11.8	15.3	12.5	
14	5.6	10.3	3.3	4.7	(10.0)	19.4	11.2	
	(17.9)	23.2	17.3	(5.3)	11.7	14.8	10.8	
15	6.3	10.9	4.3	4.6	(10.4)	18.6	12.4	
	(18.6)	—	18.0	—	11.7	—	9.6	
16	7.0	1.0	5.3	(6.4)	(10.7)	15.1	13.6	
	(19.3)	11.5	18.9	4.5	11.9	17.9	8.6	
17	7.7	2.5	6.9	(7.2)	(11.6)	15.8	14.5	
	(20.0)	12.3	19.7	4.6	12.0	17.4	7.9	
Sums; carried forward				159.0	366.2	586.8	350.2	

FIGURE 24.—Form 138, high and low waters (front).

pressed in hours and tenths, the hours being numbered consecutively from 0 (midnight) to 23 (11 p. m.). A high or low water occurring at midnight (0^h) is taken as belonging to the day just beginning. Standard time is to be used consistently throughout the tabulations regardless of any temporary local use of daylight-saving time. In form 138 two lines are provided for each calendar day, and in general

the morning tides will be entered on the first line and the afternoon tides on the second line for the day. Blank spaces should be left for tides missing because of lost record in order that inferred values may later be interpolated if desired; but when only a single

Form 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Ed. Feb., 1928

TIDES: HIGH AND LOW WATERS

Station: Seattle, Washington.

Highest tide: Date 1st & 13th Height 20.2 ft. Lowest tide: Date 6th Height 4.1 ft.

$(K_1+O_1)\div M_2$ or $2(DHQ+DLQ)\div Mn=$ 1.2 $F(Mn)=$ 1.004 $F_1=$ 0.85

DATE Year 1928	MOON'S TRANSITS (Greenwich mean civil)	TIME OF— High Water	TIME OF— Low Water	LUNITIDAL INTERVAL High Water	LUNITIDAL INTERVAL Low Water	HEIGHT OF— High Water	HEIGHT OF— Low Water	REMARKS
mo. d.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	feet	feet	
Brought forward				159.0	366.2	586.8	350.2	
Jan 18	8.4	3.4	8.0	(7.4)	(12.0)	16.7	15.0	
	(20.8)	13.0	20.3	4.6	11.9	17.2✓	7.1✓	
19	9.2	4.2	9.0	(7.4)	(12.2)	17.5✓	15.4	
	(21.7)	13.8	20.9	4.6	11.7	17.3	6.5✓	
20	10.1	4.9	9.8	(7.2)	(12.1)	18.2✓	15.4	
	(22.6)	14.3	21.7	4.2	11.6	17.6	6.2✓	
21	11.0	5.5	10.5	(6.9)	(11.9)	19.0✓	15.9	
	(23.5)	15.0	22.2	4.0	11.2	18.3	6.2✓	
22	11.9	6.0	11.1	(6.5)	(11.6)	19.7✓	15.8	
	—	16.0	22.9	4.1	11.0	18.6	5.7✓	
23	(0.4)	6.4	11.9	(6.0)	(11.5)	19.6✓	15.0	
	12.9	16.7	23.4	3.8	10.5	18.1	5.3✓	
24	(1.3)	7.0	—	(5.7)	—	19.5✓	—	
	13.8	17.3	12.4	3.5	(11.1)	18.1	14.4	
25	(2.2)	7.5	0.1	(5.3)	10.3	19.6✓	5.6✓	
	14.6	18.1	13.1	3.5	(10.9)	17.7	13.6	
26	(3.0)	8.0	0.9	(5.0)	10.3	19.4✓	6.3✓	
	15.5	19.0	14.0	3.5	(11.0)	16.8	12.4	
27	(3.9)	8.5	1.6	(4.6)	10.1	19.5✓	7.1✓	
	16.3	20.2	15.0	3.9	(11.1)	16.4	11.6	
28	(4.7)	9.0	2.3	(4.3)	10.0	20.0✓	9.0✓	
	17.1	21.5	16.0	4.4	(11.3)	16.1	10.7	
29	(5.5)	9.9	3.3	(4.4)	10.2	20.1✓	11.2	
	17.9	23.2	16.9	5.3	(11.4)	16.0	9.5✓	
30	(6.3)	10.7	4.3	(4.4)	10.4	19.5✓	13.2	
	18.8	—	17.8	—	(11.5)	—	8.1✓	
31	(7.2)	0.9	6.0	6.1	11.2	16.6	14.7	
	19.7	11.4	18.4	(4.2)	(11.2)	19.9✓	7.3✓	
Sums				59 293.8	60 667.4	59 1079.8	60 634.4	
	Unreduced intervals			4.98	11.12	18.30	10.57	
	Greenwich intervals			0.56	6.70	10.57		
	Local intervals			4.54	10.68	7.73	Mn	
						14.44	MTL	

	HHW	LLW	
	31 599.7	29 204.7	Sums
	19.35	7.06	Means
	Mn	DHQ	DLQ
Observed	7.73	1.05	3.51
Factor	1.004	0.85	0.85
Corrected	7.76	0.89	2.98

Tabulated by P. L. B. Date Feb 15, 1928 Checked by E. C. M.
Reduced by E. C. M. Date Feb. 16, 1928 Checked by W. H. M.

U. S. GOVERNMENT PRINTING OFFICE 1928 11—671

FIGURE 25.—Form 138, high and low waters (back).

high or low water actually occurs on any calendar day, the unused space may be filled with a dashed line.

215. In selecting the time of high or low water from the tide curve attention should be given to the general trend of the curve rather than the individual peaks arising from various causes. The aim

should be to take the middle of a smooth arc covering an hour or more during the high or low water period. It is not necessary to actually draw such an arc, but the point at which a smoothed curve would have reached its maximum or minimum should be estimated as closely as possible. In determing the times of the high and low waters to the nearest tenth of an hour it may be found convenient to construct a small scale 1 inch long and divided into 10 equal parts for use between the hour marks on the curve. An experienced tabulator, however, will usually be able to estimate the tenth accurately without the use of such a scale.

216. Heights.—The high and low water heights are to be tabulated in feet and tenths and should refer to a uniform datum throughout the entire series of observations. In general the datum adopted for the tabulation is the zero of the tide staff as originally installed at the station, allowances being made for any subsequent change in elevation. However, any other datum may be adopted for the tabulations, but it is desirable that the datum be sufficiently low to avoid many negative readings.

217. When tabulating from a portable gage record, the heights may be taken directly from the scale of the profile paper provided the gage has been consistently kept adjusted to agree with the tide staff readings, but allowances must be made for any material variations from such an adjustment.

218. When tabulating from the standard gage record, a glass scale, graduated to conform to the scale of the record is used. A line is ruled across the underside of this scale to correspond to the corrected scale setting as computed on form 455 (pars. 205–212). The scale is then moved along the record with this line in coincidence with the datum line on the record, the heights as read on the scale being referred directly to the desired datum. At any change in the adjustment of the automatic gage, the scale setting must be changed to accord with the new setting as computed in form 455.

HOURLY HEIGHT TABULATION

219. The hourly heights are tabulated in form 362 (fig. 26). Unless otherwise directed these heights will be tabulated in yearly series, beginning with January 1 as the first day of each series. The days are to be entered consecutively, 7 days to the page and using both sides of the form, without regard to change in calendar months or to the time of changing the tide roll. The side of the form having the wider margin on the left side should be used as the first page of each sheet. The "day of series" will be numbered consecutively through the year, beginning with "1" for the first day of January. If any part of the record is lost, blank spaces should be left for later interpolation of the missing tides. As stencils are to be used in connection

with this form, it is important that the tabulated heights be written within the spaces provided, these spaces being indicated by the printed decimal points.

Form 362
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

TIDES: HOURLY HEIGHTS

Station: Seattle, Washington Year: 1928
Observer: W. C. Meyer Lat. 47° 37′ Long. 122° 20′
Time Meridian: 120° W Tide Gauge No. 96 Scale 1: 24 Reduced to Staff of 1904

GOVERNMENT PRINTING OFFICE 11—792

Month and Day	mo. Jan d. 1	d. 2	d. 3	d. 4	d. 5	d. 6	d. 7	Horizontal Sum
Day of Series	1	2	3	4	5	6	7	
Hour	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
0	15.1	15.5	15.4	13.9	12.0	9.0	6.6	87.5
1	14.4	15.7	16.6	15.9	14.8	12.1	9.5	99.0
2	13.5	15.4	17.0	17.3	17.1	15.1	12.8	108.2
3	12.5	14.8	16.9	17.9	18.6	17.5	15.8	114.0
4	11.7	14.0	16.5	17.8	19.2	19.0	18.0	116.2
5	11.6	13.3	15.7	17.3	19.1	19.6	19.4	116.0
6	12.3	13.2	14.9	16.4	18.5	19.5	19.8	114.6
7	13.7	13.7	14.6	15.5	17.4	18.7	19.5	113.1
8	15.4	15.0	15.0	15.0	16.3	17.6	18.6	112.9
9	17.6	16.5	15.9	15.2	15.6	16.3	17.1	114.2
10	19.2	18.2	17.2	16.0	15.8	15.6	15.9	117.9
11	20.1	19.4	18.5	17.2	16.6	15.6	15.1	122.5
Noon	19.9	19.8	19.4	18.4	17.7	16.3	15.4	126.9
13	19.0	19.3	19.7	19.2	18.7	17.5	16.2	129.6
14	17.3	18.0	18.9	19.2	19.5	18.4	17.3	128.6
15	15.0	15.9	17.3	18.2	19.4	19.0	18.5	123.3
16	12.2	13.1	14.8	16.3	18.1	18.6	18.9	112.0
17	10.3	10.5	11.9	13.6	15.9	17.1	18.4	97.7
18	9.5	8.5	9.2	10.5	13.0	14.7	16.8	82.2
19	9.7	7.8	7.4	7.8	9.8	11.5	14.1	68.1
20	10.5	8.3	6.7	6.1	7.0	8.1	10.9	57.6
21	11.8	9.5	7.5	5.8	5.3	5.6	7.8	53.3
22	13.4	11.4	9.1	7.0	5.1	4.2	5.4	55.6
23	14.8	13.6	11.4	9.1	6.6	4.6	4.2	64.3
Sum	340.5	340.4	347.5	346.6	357.1	351.2	352.0	2435.3

Sum for = Divisor=(28d) 672; (29d) 696; (30d) 720; (31d) 744. Mean for month=

Tabulated by P. L. B. Date Feb. 15, 1928 Summed by W. H. M. Date Mar. 14, 1928

FIGURE 26.—Form 362, hourly heights.

220. As a check on the arrangement of the days in the form, the following table gives the page, column of page, and day of series, for

the first of each calendar month, when the series commences with January 1:

Common year				Leap year			
Month	Page	Column	Day of series	Month	Page	Column	Day of series
Jan. 1	1	1	1	Jan. 1	1	1	1
Feb. 1	5	4	32	Feb. 1	5	4	32
Mar. 1	9	4	60	Mar. 1	9	5	61
Apr. 1	13	7	91	Apr. 1	14	1	92
May 1	18	2	121	May 1	18	3	122
June 1	22	5	152	June 1	22	6	153
July 1	26	7	182	July 1	27	1	183
Aug. 1	31	3	213	Aug. 1	31	4	214
Sept. 1	35	6	244	Sept. 1	35	7	245
Oct. 1	40	1	274	Oct. 1	40	2	275
Nov. 1	44	4	305	Nov. 1	44	5	306
Dec. 1	48	6	335	Dec. 1	48	7	336
Dec. 31	53	1	365	Dec. 31	53	2	366

221. The tabulated hourly heights are to be expressed in feet and tenths and will be referred to the same datum as adopted for the high and low waters, the heights being scaled from the record in the same manner as described for the high and low water tabulations. The hourly heights are to be taken on the exact hour and allowance must be made for any time error in the record. This is especially necessary if the heights are to be used in an harmonic analysis of the observations.

222. Tide observers who tabulate their own records should retain at the end of each month the last incomplete sheet of the hourly heights in order that it may be completed when the record for the following month is available.

INTERPOLATIONS

223. Before beginning the reductions, if any portion of the record is lost, it is desirable that the missing tides be supplied by interpolation. Interpolated tides should be enclosed in brackets to distinguish them from observed tides.

224. If the heights of alternate high waters are plotted on cross-section paper it will be found that fairly smooth curves may be drawn through the plotted points. Such a graph affords a means of interpolating for missing high waters where only a few tides have been lost. When only a few tides are missing the alternate heights for several days before and several days after the break may be plotted and spaces left for the missing values. The smooth curve connecting the observed values will generally determine the missing values with sufficient accuracy. Similar curves may be drawn for alternate low waters. The times as well as the heights will be found to plot in

fairly regular curves, and times of missing high and low waters may also be determined by this graphic method.

225. Another method of supplying missing values is by direct comparison with simultaneous observations at some other station in the vicinity. This method is especially useful in extrapolating values at the beginning and end of a series of observations.

LUNITIDAL INTERVALS

226. A Greenwich lunitidal interval is the absolute difference in time between the transit of the moon over the meridian of Greenwich and the time of the occurrence of the following high or low water at any place, separate intervals being obtained for the high and low waters. A local lunitidal interval is the difference in time between the transit of the moon over the local meridian and the time of the following high or low water at a place on the same meridian. The mean local high-water intervals for many places are included in the annual tide tables of this Bureau. The Greenwich intervals have the advantage that they afford a direct means for obtaining the difference in the time of tide at different places.

227. Form 138 (figs. 24, 25) in which the high and low waters are tabulated provides for the computation of both high and low water lunitidal intervals. The Greenwich transits in hours and tenths, which will be furnished upon request or which may be derived from the American Ephemeris and Nautical Almanac where they are given in hours and minutes, are to be entered in the column of "Moon's transits," the lower transits being distinguished from the upper transits by being enclosed in parentheses.

228. From the time of each high and low water subtract the time of the first preceding moon's transit and enter the difference in the appropriate column of the form and on the same line as the tide from which it was obtained. In case the time of high or low water is nearly the same as that of the moon's transit, take the transit which precedes the tide by about 12 hours, but in no case must the same transit be used for two consecutive high waters or for two consecutive low waters. The lower transit of the moon applies to both high and low water, just the same as the upper transit does. When the time of the moon's transit is on one day and the following high or low water is on the next day the time of this tide must be increased by adding 24 hours before attempting to subtract the time of the transit. The high-water intervals will usually be approximately 6 hours greater or less than the low-water intervals, but the intervals for each phase of tide will usually agree among themselves within an hour or two. Intervals from the lower transits of the moon are to be indicated by parentheses. The high and low water intervals for the calendar month are summed separately and the means obtained to two decimal places.

229. In these computations the moon's transits are given in Greenwich time while the high and low waters are given in the standard time of the place of observations. To obtain the Greenwich lunitidal intervals it is therefore necessary to apply a correction corresponding

to the time meridian of the place of observation, the correction to be added for west longitude and subtracted for east longitude. In figure 25, the mean unreduced high and low water intervals for Seattle for the month represented are 4.98 hours and 11.12 hours, respectively. As the time meridian for Seattle is 120° or 8 hours west, a correction of +8 hours must be applied to each of these intervals giving 12.98 hours and 19.12 hours, respectively, from which the lunar semidiurnal period of 12.42 hours may be rejected, leaving 0.56 hours and 6.70 hours, respectively, as the Greenwich high and low water lunitidal intervals from this particular series of observations.

230. Local lunitidal intervals.—To change from Greenwich to local intervals, it is necessary to apply a correction equal to the time required for the moon to pass from the meridian of Greenwich to the meridian of the place of observations. A table (p. 73) has been prepared giving the correction for each degree of longitude from 1° to 180°, and the value for each minute of arc from 1′ to 60′ for interpolating between the whole degrees. In changing from Greenwich to local intervals, the tabular value is to be subtracted if the place of observation is in west longitude and added if in east longitude. In order that the local intervals may be positive and less than the half lunar day, the lunar semidiurnal period of 12.42 hours may be added or subtracted as desired. The longitude of Seattle, which is used as an example in figure 25, in 122°20′. In the table on page 73 we find the corrections corresponding to 122° and 20′ to be 8.418 hours and 0.023 hours, respectively. Combining these we have 8.44 hours as the difference between Greenwich and local intervals at Seattle, and as Seattle is in west longitude this difference is to be subtracted from the Greenwich intervals. To avoid negative results, the Greenwich intervals are first increased by adding the semidiurnal period of 12.42 hours, after which the difference 8.44 hours is subtracted leaving 4.54 hours and 10.68 hours, respectively, as the local high and low water lunitidal intervals for these observations.

231. Method of checking intervals.—The mean unreduced intervals as obtained above may be conveniently checked by the following method:

(*a*) Sum times of moon's transits occurring during month. The number of transits will usually be two less than twice the number of days in the month; that is, 54 for a 28-day month, 56 for a 29-day month, 58 for a 30-day month, and 60 for a 31-day month. For the sake of uniformity, if the number of transits should be one greater than this, the last transit must be omitted from the sum and the last day be considered as having only the single value. On the other hand, if the number of transits should be one less than the usual number, the deficiency must be supplied by including the last transit of the preceding month. From the sum of the transits subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single transit occurs. For example, if single transits occur on the 3d and 17th of a month, the sum 20 is multiplied by 24, and the product 480 hours is then subtracted from the sum of the transits. Designate the remainder by T, which may be either positive or negative.

(*b*) Sum separately the times of high and low waters, limiting the number of items in each case to two less than twice the number of days in the month, following the method described for the summation of the moon's transits. From the sum of the time of the high waters subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single high water occurred, and from the sum of the times of the low water subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single low water occurred. Designate these results by H and L, respectively.

(*c*) Find the differences (H−T) and (L−T) and divide by the number of items included in each summation, which should be twice the number of days in the month less two. Such multiples of 12.42 hours may be applied or rejected from the means as may be necessary to reduce them to positive values of less than 12.42 hours. The results obtained should check very closely with unreduced means as obtained directly from the individual intervals, although at times there may be a small difference in the second decimal place.

232. Example.—This method for checking the mean intervals is illustrated below for Seattle, Wash., for the month of January 1928, these intervals having been computed in the regular manner in figures 24 and 25. This being a 31-day month, the number of items included in each summation must be 60.

Sum of times of 60 transits, January 1928	727.6
24×(7+22), single transits occuring Jan. 7 and 22	696
Difference (T)	31.6
Sum of times of 59 high waters, January 1928	665.7
Time of high water Dec. 31, 1927, for deficiency	23.2
Sum of times of 60 high waters	688.9
24×(1+15+30), single high waters occurring Jan. 1, 15, and 30	1,104
Difference (H)	−415.1
Sum of times of 60 low waters, January 1928	745.6
24×(9+24), single low waters occurring Jan. 9 and 24	792
Difference (L)	−46.4

(H−T)÷60=−446.7÷60=−7.44 hours for high-water interval.

(L−T)÷60=−78.0÷60=−1.30 hours for low-water interval.

Applying the tidal period 12.42 hours to each of the above negative intervals, we have 4.98 and 11.12 hours, respectively, for the unreduced high and low water intervals. It will be noted that these results agree exactly with those obtained in figure 25 by the regular computations. An exact agreement, however, is not always to be expected, but the results will usually agree within 1 or 2 hundredths of an hour.

233. Lunitidal intervals from Form 248.—For a short series of observations the lunitidal intervals can be computed in Form 248

(fig. 27) from a comparison with simultaneous observations at a standard station suitably situated. The form provides for the computation of the local intervals and contains an explanation of its use

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
Form 248
Ed. May, 1928

TIDES : Comparison of Simultaneous Observations

(A) Subordinate station Anacortes, Wash. Lat. 48° 31' N. Long. 122° 36' W.
(B) Standard station Seattle, Wash. Lat. 47° 37' N. Long. 122° 20' W.
Chief of party .... Time Meridian: (A) 120° W. (B) ....

DATE.	(A) STATION.		(B) STATION.		(A)—(B)		(A) STATION.		(B) STATION.		(A)—(B)	
Year.	Time of—		Time of—		Time difference.		Height of—		Height of—		Height difference.	
1922	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.
No. D.	Hours.	Hours.	Hours.	Hours.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Sept. 24	7.4	0.1	7.2	0.6	0.2	-0.5	22.7	15.4	18.3	7.3	4.4	8.1
	18.5	12.3	18.8	13.0	-0.3	-0.7	23.2	18.7	19.2	11.0	4.0	7.7
25	8.6	1.0	8.0	1.5	0.6	-0.5	22.6	15.0	18.2	7.0	4.4	8.0
	18.9	13.0	19.4	13.8	-0.5	-0.8	22.9	19.6	18.7	12.3	4.2	7.5
26	9.9	1.9	9.4	2.3	0.5	-0.4	22.9	15.2	18.1	7.3	4.6	7.9
	20.0	14.4	20.5	15.0	-0.5	-0.6	22.9	20.7	18.4	13.5	4.5	7.2
27	11.0	2.9	10.4	3.2	0.6	-0.3	23.0	15.7	18.1	8.0	4.9	7.7
	20.5	16.0	21.5	16.4	-1.0	-0.4	22.1	20.9	17.1	13.8	5.0	7.1
28	12.5	4.0	12.0	4.3	0.5	-0.3	22.7	15.6	18.0	8.2	4.7	7.4
	21.6	18.0	22.9	17.8	-1.3	-0.2	21.0	20.4	16.1	13.6	4.9	6.8
29	13.5	5.0	----	5.5	0.6	-0.5	22.7	15.8	----	8.3	4.7	7.5
	23.2	19.0	12.9	19.0	-0.9	0.0	20.7	20.0	18.0	13.0	4.9	7.0
30	----	6.0	0.1	6.6	---	-0.6	----	16.3	15.8	8.9	---	7.4
	14.3	20.4	14.0	20.0	0.3	0.4	23.2	19.8	18.4	12.7	4.6	7.1
Sums							HHW. 7 160.6	HLW. 7 140.3	HHW. 7 128.8	HLW. 7 89.9	HHW. 7 31.6	HLW. 7 50.4
Means							22.94	20.04	18.40	12.84	4.54	7.20
Sums					13 -1.2	14 -5.0	LHW. 6 132.0	LLW. 7 109.0	LHW. 6 103.6	LLW. 7 55.0	LHW. [illegible] 28.4	LLW. 7 54.0
Means					-0.09	-0.36	22.00	15.57	17.27	7.86	4.73	7.71

	HW.	LW.	
(1)=	-0.09	-0.36	=Mean difference in time of high and low water respectively.
(2)=	-0.02	-0.02	=Correction for difference in longitude. (Table on back of form.)
(3)=	-0.11	-0.38	=(1)+(2)=Mean difference in high and low water intervals, respectively.

Feet. Feet.

(4)= 22.94 =Mean HHW height at (A). (5) = 20.04 =Mean HLW height at (A).
(6)= 22.00 =Mean LHW height at (A). (7) = 15.57 =Mean LLW height at (A).
(8)= 0.94 =(4)−(6)=2DHQ at (A). (9) = 4.47 =(5)−(7)=2DLQ at (A).
(10)= 22.47 =½[(4)+(6)]=Mean HW height at (A). (11)= 17.80 =½[(5)+(7)]=Mean LW height at (A).
(12)= 4.67 =(10)−(11)=Mn at (A). (13)= 20.14 =½[(10)+(11)]=MTL at (A).

(14)= 4.54 =Mean HHW difference. (15)= 7.20 =Mean HLW difference.
(16)= 4.73 =Mean LHW difference. (17)= 7.71 =Mean LLW difference.
(18)= -0.19 =(14)−(16)=2DHQ difference. (19)= -0.51 =(15)−(17)=2DLQ difference.
(20)= 4.64 =½[(14)+(16)]=Mean HW difference. (21)= 7.46 =½[(15)+(17)]=Mean LW difference.
(22)= -2.82 =(20)−(21)=Mn difference. (23)= 6.05 =½[(20)+(21)]=MTL difference.

(24)= 0.623 =(12)÷[(12)−(22)]=Mn ratio. (25)= 0.832 =(8)÷[(8)−(18)]=DHQ ratio.
(26)= 0.898 =(9)÷[(9)−(19)]=DLQ ratio.

Results from comparison of Stations A and B.	HWI.	LWI.	MTL.	Mn.	DHQ.	DLQ.
Length of Series.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.
Accepted values for standard station, from obs. for 19 years	4.48	10.70	14.06	7.64	0.86	2.83
Differences and ratios: (3), (23), (24), (25), (26)	-0.11	-0.38	6.05	×0.623	×0.832	×0.898
Corrected values for subordinate station	4.37	10.32	20.11	4.76	0.72	2.54

Mean LW on staff at subordinate station=MTL−½Mn = ... feet.
Mean LLW on staff at subordinate station=MTL−½Mn−DLQ= 15.19 feet.

Computed by C. D. A., 5 - 12 - 27 (Date.) Verified by F.J.H., 5 - 12 - 27 (Date.)
11—6244

FIGURE 27.—Form 248, comparison of simultaneous observations.

on the back. The table on page 73 may be used to obtain the correction for difference in longitude. The Greenwich lunitidal intervals at the subordinate station may be obtained by the simple application of the mean differences in the time of high and low water to the corresponding Greenwich intervals at the standard station.

Table for reducing Greenwich intervals to local intervals

Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction
′	Hour	′	Hour	°	Hour	°	Hour	°	Hour	°	Hour	°	Hour	°	Hour
1	0.001	31	0.036	1	0.069	31	2.139	61	4.209	91	6.279	121	8.349	151	10.420
2	.002	32	.037	2	.138	32	2.208	62	4.278	92	6.348	122	8.418	152	10.489
3	.003	33	.038	3	.207	33	2.277	63	4.347	93	6.417	123	8.487	153	10.558
4	.005	34	.039	4	.276	34	2.346	64	4.416	94	6.486	124	8.556	154	10.627
5	.006	35	.040	5	.345	35	2.415	65	4.485	95	6.555	125	8.625	155	10.696
6	.007	36	.041	6	.414	36	2.484	66	4.554	96	6.624	126	8.694	156	10.765
7	.008	37	.043	7	.483	37	2.553	67	4.623	97	6.693	127	8.763	157	10.834
8	.009	38	.044	8	.552	38	2.622	68	4.692	98	6.762	128	8.832	158	10.903
9	.010	39	.045	9	.621	39	2.691	69	4.761	99	6.831	129	8.901	159	10.972
10	.012	40	.046	10	.690	40	2.760	70	4.830	100	6.900	130	8.970	160	11.041
11	.013	41	.047	11	.759	41	2.829	71	4.899	101	6.969	131	9.039	161	11.110
12	.014	42	.048	12	.828	42	2.898	72	4.968	102	7.038	132	9.108	162	11.179
13	.015	43	.049	13	.897	43	2.967	73	5.037	103	7.107	133	9.177	163	11.248
14	.016	44	.051	14	.966	44	3.036	74	5.106	104	7.176	134	9.246	164	11.317
15	.017	45	.052	15	1.035	45	3.105	75	5.175	105	7.245	135	9.315	165	11.386
16	.018	46	.053	16	1.104	46	3.174	76	5.244	106	7.314	136	9.384	166	11.455
17	.020	47	.054	17	1.173	47	3.243	77	5.313	107	7.383	137	9.453	167	11.524
18	.021	48	.055	18	1.242	48	3.312	78	5.382	108	7.452	138	9.522	168	11.593
19	.022	49	.056	19	1.311	49	3.381	79	5.451	109	7.521	139	9.591	169	11.662
20	.023	50	.058	20	1.380	50	3.450	80	5.520	110	7.590	140	9.660	170	11.731
21	.024	51	.059	21	1.449	51	3.519	81	5.589	111	7.659	141	9.729	171	11.800
22	.025	52	.060	22	1.518	52	3.588	82	5.658	112	7.728	142	9.798	172	11.869
23	.026	53	.061	23	1.587	53	3.657	83	5.727	113	7.797	143	9.867	173	11.938
24	.028	54	.062	24	1.656	54	3.726	84	5.796	114	7.866	144	9.936	174	12.007
25	.029	55	.063	25	1.725	55	3.795	85	5.865	115	7.935	145	10.005	175	12.076
26	.030	56	.064	26	1.794	56	3.864	86	5.934	116	8.004	146	10.074	176	12.145
27	.031	57	.066	27	1.863	57	3.933	87	6.003	117	8.073	147	10.143	177	12.214
28	.032	58	.067	28	1.932	58	4.002	88	6.072	118	8.142	148	10.212	178	12.283
29	.033	59	.068	29	2.001	59	4.071	89	6.141	119	8.211	149	10.281	179	12.352
30	.035	60	.069	30	2.070	60	4.140	90	6.210	120	8.280	150	10.351	180	12.421

HEIGHT REDUCTIONS

234. Form 138, on which are tabulated the high and low waters, provides for the regular computation each month of certain tidal planes and ranges. Mean high water (*HW*) and mean low water (*LW*) for each month are obtained by summing all the high waters and all the low waters and dividing by the number of observations, the latter being indicated by small figures just above the sum. The means, written below the sums, should be carried to two decimal places. The mean range (*Mn*) is obtained by subtracting the mean of the low waters from the mean of the high waters. The mean tide level (*MTL*), which is also known as half-tide level, is obtained by taking the half sum of the mean of the high waters and the mean of the low waters.

235. For stations on the Pacific coast, the means of the higher high waters and of the lower low waters and the diurnal inequalities should also be obtained. The higher of the two high waters and the lower of the two low waters of each day of the month are first indicated by a check mark. If the two high or two low waters on the same day are equal, either may be selected as the higher high or lower low water. When only one high or one low water occurs on a calendar day, by reason of one of the tides having occurred after midnight and therefore on the next calendar day, the single tide is to be checked if the tide just above it is unchecked; otherwise

it should not be checked. If, however, the tide has become diurnal and only one high and one low water occur during the tidal day, these should both be checked. The checked heights are to be summed separately for the high and low waters, the sums being entered in the spaces provided, with the number of observations written above in small figures. The mean of the higher high waters (HHW) and the mean of the lower low waters (LLW) are then obtained, each result being carried to two decimal places.

236. The diurnal high water inequality (DHQ) is obtained by subtracting the mean of all high waters from the mean of the higher high waters, and the diurnal low water inequality (DLQ) is obtained by subtracting the mean of the lower low waters from the mean of all low waters.

237. Correction for longitude of moon's node.—There is a long-period variation in the range of tide due to changes in the inclination of the moon's orbit to the Equator. When the longitude of the moon's node is 0° the inclination of the orbit to the Equator is at a maximum and the average range of the four tides of the day is less than usual; and when the longitude of the moon's node is 180° the inclination is at a minimum and this range of tide is greater than usual. The time required for the longitude of the moon's node to pass through the cycle of 360° is approximately 19 years. In addition to the variations caused by changes in the longitude of the moon's node, the diurnal inequalities are subject to variations from month to month caused by changes in the declination of the sun. Because of these variations certain factors are necessary in order to reduce to mean values the ranges and inequalities obtained from short series of observations. At the primary tide stations, the correction need not be applied to the results for each individual month, it being sufficient to correct the annual means as needed. If the series of observations extends over a period of 19 years, the factors are unnecessary.

238. Tables containing the factor $F(Mn)$ for reducing the observed range of tide to its mean value and factor F_1 for reducing the diurnal inequalities DHQ and DLQ to their mean values are given on page 75. These tables cover the years 1941 to 1950, inclusive, and are based upon tables 6, 14, and 32 of Harris' Manual of Tides. Similar tables covering the years 1891 to 1950, inclusive, will be found in Special Publication No. 135, Tidal Datum Planes. The factor $F(Mn)$ was computed for the middle of each calendar year, but as the factor changes very slowly, the tabular value may be used for any month in the year without material error. The factor F_1 was computed for the middle of each calendar month. The table includes also the mean of the monthly factors for each year which may be taken as the factor for correcting the yearly inequalities to their mean values.

239. The factor $F(Mn)$ depends not only upon the year of observation but also upon the relation of the diurnal to the semidiurnal wave in the locality, this relation being expressed approximately by the formula $\frac{2(DHQ+DLQ)}{Mn}$, or if harmonic constants are available by the ratio $\frac{K_1+O_1}{M_2}$. For stations along the Atlantic coast of the United States from Maine to Florida this relation is generally small, and, if

not already computed, may be assumed to be less than 0.2 without material error. For stations along the Gulf of Mexico from Key West to the Rio Grande the mean range of tide is very small and the correcting factor may be omitted. For stations on the Pacific coast the value of the ratio may be computed either from the inequalities or from the harmonic constants but need be carried to only one decimal place. If this ratio is larger than 2.0, no correction need be applied to the mean range.

Factor F (Mn).—For reducing the observed range of tide to its mean value

$\frac{2(DHQ+DLQ)}{Mn}$	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
0.0 to 0.2	0.971	0.972	0.977	0.985	0.995	1.005	1.014	1.023	1.028	1.029
0.3 to 0.4	.972	.973	.978	.985	.995	1.005	1.014	1.022	1.027	1.028
0.5 to 0.6	.974	.975	.979	.986	.995	1.005	1.013	1.021	1.025	1.026
0.7 to 0.8	.976	.977	.981	.987	.996	1.004	1.012	1.018	1.022	1.023
0.9 to 1.0	.979	.980	.984	.990	.996	1.004	1.010	1.016	1.019	1.020
1.1 to 1.2	.983	.984	.987	.992	.997	1.003	1.008	1.013	1.016	1.017
1.3 to 1.4	.987	.988	.991	.994	.998	1.002	1.006	1.009	1.012	1.013
1.5 to 1.6	.992	.993	.994	.997	.999	1.001	1.004	1.006	1.007	1.008
1.7 to 1.8	.999	.999	.999	.999	1.000	1.000	1.001	1.001	1.001	1.001
1.9 to 2.0	1.006	1.006	1.005	1.003	1.001	0.999	0.997	0.996	0.995	0.994

Factor F_1.—For correcting DHQ and DLQ

Month	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
January	1.01	1.01	0.98	0.95	0.90	0.87	0.83	0.81	0.79	0.79
Feburary	1.22	1.21	1.18	1.13	1.06	1.01	0.97	0.94	0.91	0.90
March	1.46	1.45	1.39	1.31	1.23	1.16	1.11	1.07	1.04	1.03
April	1.34	1.33	1.28	1.21	1.14	1.08	1.03	1.00	0.98	0.97
May	1.07	1.07	1.03	0.99	0.94	0.90	0.87	0.84	0.83	0.82
June	0.96	0.96	0.93	0.89	0.85	0.82	0.79	0.77	0.76	0.76
July	1.00	0.99	0.96	0.92	0.88	0.84	0.82	0.80	0.78	0.78
August	1.22	1.20	1.15	1.09	1.04	0.99	0.95	0.93	0.91	0.91
September	1.47	1.43	1.36	1.29	1.20	1.14	1.09	1.06	1.04	1.04
October	1.33	1.30	1.24	1.17	1.10	1.05	1.01	0.98	0.96	0.96
November	1.07	1.04	1.00	0.96	0.91	0.88	0.85	0.83	0.82	0.82
December	0.96	0.94	0.91	0.87	0.83	0.80	0.78	0.76	0.76	0.76
Mean	1.176	1.161	1.118	1.065	1.007	0.962	0.925	0.899	0.882	0.878

240. Comparison of simultaneous observations.—For a short series of observations, reduction by comparison of simultaneous observations is generally the best method provided there is a suitable standard tide station from which the necessary simultaneous data may be obtained. For this purpose the standard station should be so situated that the effects of meteorological conditions may be expected to be similar to those at the station for which the results are sought. A reference to the use of this method in computing lunitidal intervals has already been made in paragraph 233. The process is especially valuable in the reduction of the heights of the tide. For observations covering a period of less than 1 month, form 248 is generally used, but for series extending over longer periods, form 657 for the comparison of monthly means will be found more convenient. The latter form is self-explanatory.

241. Form 248 (fig. 27) is designed to bring out the individual differences between the tides at the two stations compared, the accuracy of the resulting means depending somewhat upon the uniformity of these differences. If any single difference varies greatly from the apparent average of its group, and an examination of the original data fails to show an error, the difference should be rejected from the sum and the fact indicated by encircling the rejected value. For stations where the diurnal inequalities are desired, the higher high waters, lower high waters, higher low waters, lower low waters, and their differences are summed and averaged separately; and all the spaces in the bottom portion of form 248 are filled in. If the diurnal inequalities are not needed, as is generally the case for stations on the Atlantic coast, all high waters and corresponding differences may be summed and averaged without distinction and likewise all low waters and differences, the notations at the bottom of the columns being corrected to read *HW* and *LW*. The mean high and low water heights for (A) station will then be entered directly as items (10) and (11) in the form, and the mean differences from the last two columns as items (20) and (21). The form will then be completed as far as necessary to obtain the results desired.

TIDAL DATUMS

242. A tidal datum is a plane or surface which may be defined by the tides and which is used as a reference for heights or depths. The principal tidal datums now in use by this Survey are (1) *mean sea level*, the datum of the first-order level net and in general use as a reference for heights; (2) *mean low water*, the datum of soundings on charts of the Atlantic coast of the United States; (3) *mean lower low water*, the datum of soundings on charts of the Pacific coast of the United States, Alaska, Hawaii, and the Philippine Islands; and (4) *mean low water springs*, the datum for the Pacific coast of the Canal Zone and in more or less general use as the datum of charts published by foreign countries.

243. Mean sea level.—Mean sea level may be defined as the average height of the sea for all stages of the tide. It is obtained by averaging the hourly heights as tabulated in form 362. The heights in this form are summed both vertically and horizontally, and the total page sum covering 7 days of record is entered in the lower right corner of the page. For a continuing series of observations, the mean for each calendar month is obtained by combining all the daily sums for the month and dividing by the total number of hours as indicated at the bottom of the form for months of different lengths. The monthly mean carried to two decimal places is entered at the bottom of the sheet containing the record for the last day of the month.

244. Form 472a provides for the compilation of the monthly means and the computation of the yearly means from the same. It also provides for an accumulative mean combining all yearly means up to date. The precision of an independent determination of mean sea level depends largely upon the number of years of observations. In general a series covering not less than 3 years should be obtained for an independent determination of the datum. For a shorter series of observations, the sea level as directly obtained should be reduced by comparison with simultaneous observations provided there is a pri-

mary tide station suitably located from which the necessary data for the comparison may be obtained. Form 657 for the comparison of monthly means may be used for this reduction.

245. The name "mean sea level" should be applied only to the datum derived from observations taken on the open coast or in adjacent waters having free access to the sea. The average of the hourly heights taken in a river is called "mean river level" and is higher than the mean sea level because of the river slope. The plane of half-tide level derived from the high and low waters approximates very closely to the mean sea level or mean river level determined from the hourly heights. For any one station the difference remains nearly constant from month to month and affords a convenient check on the work when both planes are computed.

246. Mean low water.—Mean low water is generally adopted as a datum for hydrographic operations along the Atlantic coast of the United States. It may be defined as the mean of all low waters over a considerable period of time. The datum may be derived independently from a long series of observations, but from a short series can best be obtained from a comparison of simultaneous observations at a nearby standard station (pars. 240–241). For the longer series, the range of tide is corrected for the longitude of the moon's node (pars. 237–239), and one-half of the corrected range is then subtracted from the half-tide level to obtain the corrected mean low water. When reduction is made by a comparison of simultaneous observations both range and half-tide level are subject to correction, and the corrected mean low water is obtained by subtracting one-half the corrected range from the corrected half-tide level.

247. Mean lower low water.—This datum is generally adopted for hydrographic operations along the Pacific coast of the United States and may be defined as the mean of the lower of the two low waters of each day over a considerable period of time. When determined independently from a long series of observations, the mean range and diurnal low water inequality must be corrected for the longitude of the moon's node as explained in paragraphs 237–239. The corrected mean lower low water is then obtained by subtracting from the half-tide level height the sum of the corrected half range and the corrected diurnal low water inequality. For a short series of observations, the mean lower low water datum may be computed by means of form 248 for the comparison of simultaneous observations (pars. 240–241).

248. Mean low water springs.—While datums approximating this plane have been rather generally used by foreign countries, its use by this Survey is limited to the Pacific coast of the Panama Canal Zone. The datum may be defined as the mean of the low waters of the spring tides which occur within a day or two after the moon is new or full, and may be obtained by subtracting one-half the spring range of tide from the half-tide level. Because of the limited use of this datum it is not regularly obtained at all tide stations. The most satisfactory method of obtaining the spring range of tide is from an harmonic analysis, an involved process not adapted to field use. From such analyses it has been found that the ratio of spring range to mean range is fairly constant over wide areas. For Balboa, Canal

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Zone, the ratio is 1.26, and this factor may be applied without material error to the corrected mean range at any station on the Pacific coast of the Canal Zone to obtain the spring range of tide. Therefore to obtain the datum of mean low water springs at any station in this vicinity, first compute the corrected mean range and half-tide level by methods already described. The datum may then be expressed by the formula "Mean low water springs=half-tide level$-$0.63$\times$mean range of tide." The factor may vary in other locations.

TIDE REDUCERS FOR SOUNDINGS

249. After the datum or plane of reference has been derived, the tide reducers for soundings are obtained by subtracting the reading corresponding to the datum from the recorded heights of the tide taken at intervals during the time of the soundings. The differences will in general be positive except when the tide falls below the datum. The positive differences are to be subtracted from the soundings, but when entered in the sounding books, the minus sign is usually omitted for convenience. When the tide falls below the datum, the difference is to be added to the soundings and this difference must always be prefixed by a plus sign when entered in the sounding record. Detailed instructions pertaining to the application of the tide reducers to the soundings will be found in the Hydrographic Manual (Special Publication No. 143).

250. Graphic method.—When the reduced soundings are to be given in integral feet, reductions for tide may be made easily and rapidly from either the standard automatic tide-gage or the portable automatic tide-gage marigrams by a graphic method described in the following paragraphs. In using this method care should be taken, however, to avoid confusion as to the times or the heights of tides, especially when reading from a portable automatic tide-gage record on which the curves representing the tide for different days are often close together. At times it may be necessary to strengthen a faintly traced curve of the record so that it may be sufficiently bold to be readily seen through the transparent graphic scale.

251. This scale is constructed on transparent tracing cloth or tracing paper by ruling a series of horizontal lines spaced at intervals representing feet in the same height scale as used on the marigram and a series of vertical lines spaced at intervals representing hours in the same time scale as used on the marigram. For the portable tide-gage records the vertical lines may usually be omitted. The horizontal lines are numbered upward from the bottom of the scale $+3$, $+2$, $+1$, 0, -1, -2, -3, -4, etc., according to the range of tide, small figures being used for this numbering. A horizontal line in red ink is now drawn on the tracing at the scale reading corresponding to the value of the formula $x-y-0.7$ ft., where x=height of plane of reference (*LW* or *LLW*) above zero of the tide staff, y=height of datum line of marigram as referred to zero of tide staff, and the value "0.7 ft." represents the fraction at which the reduced sounding changes by an integral foot.

For the standard tide-gage record the value of "y" is the corrected scale setting as computed on form 455 (fig. 23). For the portable tide-gage record the "0" of the marigram record may be taken as the datum line and "y" becomes equal to zero. The red line will be

above or below the zero of the scale, according to whether the value from the formula is negative or positive.

252. The graph is laid over the marigram with the red horizontal line in coincidence with the datum line if a standard gage record, or with the scale zero of the portable gage record (assuming that this corresponds to the tide staff zero), and the hour marks of the graphic scale and of the marigram in coincidence. In case a time allowance is to be made, the graph is shifted to the right or to the left, according to the amount of time allowance.

253. The spaces between the horizontal lines are numbered with figures somewhat larger than those used for the scale lines, beginning

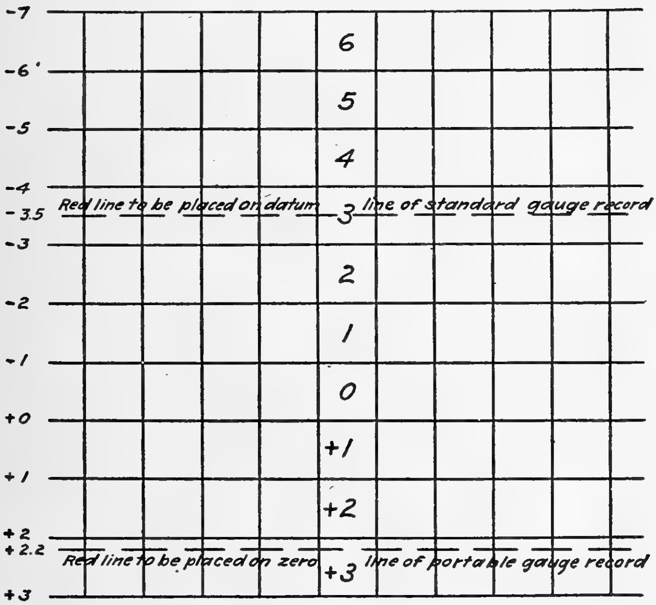

FIGURE 28.—Graph for obtaining tide reducers directly from marigram.

with "0" for the space just above the zero (0) line and numbering consecutively above and below this space, using the plus (+) sign before the numerals for the lower spaces. These numbers will be the tide reducers to integral feet for all portions of the tide curve falling within the space so marked.

254. An example of a graphic scale is given in figure 28. For the standard-gage record, assuming that "x," the height of the plane of reference above the zero of the tide staff, is 2.3 feet, and that "y," the height of the datum line above the zero of tide staff, is 5.1 feet, the formula $x-y-0.7$ gives -3.5 feet as the scale reading at which the red line is drawn, this line to be placed in coincidence with the datum line of the marigram when the scale is in use. For the portable gage assuming that "x," the height of plane of reference on tide staff, is 2.9 feet, and taking "y" as zero, the formula gives $+2.2$ feet as the scale reading for the red line, which is to be placed in coincidence with the zero of the marigram scale when in use.

255. Time allowance.—When there is much difference in the time or height of the tide at the place of sounding and at the tide gage, allowance should be made in the reduction of the soundings. The difference may generally be estimated from observations made at several stations in the vicinity of the work, but when it has been impossible to establish more than one tide station in the locality, the following formula may be useful in estimating the velocity of a progressive tidal wave and enable one to obtain the approximate difference in the time of the tide: $v=\sqrt{gd}=5.67\sqrt{d}$ feet per second, when $g=32.17$ feet per second and d=depth of water for the average cross section between stations, in feet.

In order to convert feet per second into nautical miles per hour, multiply by $\frac{3600}{6080}=0.592$, and we have

$$v=3.36\sqrt{d} \text{ nautical miles per hour}$$

The time required for the tide wave is

$$t=\frac{6080}{60\times 5.672\sqrt{d}}=\frac{17.87}{\sqrt{d}} \text{ minutes per nautical miles.}$$

$$t=\frac{5280}{60\times 5.672\sqrt{d}}=\frac{15.51}{\sqrt{d}} \text{ minutes per statute mile.}$$

For convenience the following brief table is given:

Time required for the tide wave to travel

Depth	1 nautical mile	1 statute mile	Depth	1 nautical mile	1 statute mile
Fathoms	*Minutes*	*Minutes*	*Fathoms*	*Minutes*	*Minutes*
1	7. 3	6. 3	9	2. 4	2. 1
2	5. 2	4. 5	10	2. 3	2. 0
3	4. 2	3. 7	15	1. 9	1. 6
4	3. 6	3. 2	20	1. 6	1. 4
5	3. 3	2. 8	30	1. 3	1. 2
6	3. 0	2. 6	40	1. 2	1. 0
7	2. 8	2. 4	50	1. 0	0. 9
8	2. 6	2. 2	60	0. 9	0. 8

256. For offshore areas where the continental shelf is broad and the tidal wave approaches parallel to the coast the tide will arrive offshore earlier than inshore, and for an accurate reduction of soundings a time correction will be necessary. This time correction can be applied from the shore outward by taking sections where the time of the tide averages 15 minutes, 30 minutes, 45 minutes, 1 hour, etc., earlier than at the tide station. These sections can be determined by means of the above table, giving the time required for the tide wave to travel at different depths.

257. Height Allowance.—When the tide station used for deriving the tide reducers is made to cover an area over which the range of

tide varies height corrections will be necessary. For the adjustment of tide reducers between stations along the coast and inside waters it will be found convenient to divide the area covered into sections. Each section may cover an area in which the variation in range of tide does not exceed three-tenths of the unit used for the tide reducers; that is, 0.3 foot, 0.9 foot, and 1.8 feet when the reducers are entered in units of a foot, half fathom, and whole fathom, respectively. Take, for example, an area 15 miles long with no narrow restrictions and with depths of 3 fathoms or less. At one end is station A, where tide observations have been taken during the time of the soundings; at the other end is station B, where the time differences and ratio of ranges have been determined. The mean range of tide at station A is 2.6 feet, at station B 3.5 feet, the difference in range being 0.9 foot. The difference in the time of tide between the two stations will be assumed to be 45 minutes. The area should, therefore, be divided into four sections. Assuming the tide to increase uniformly with the distance, the first section will be 2½ miles long and the height and time of the tide the same as at station A. The second section will be 5 miles long and the height of high water 0.3 foot greater and time 15 minutes later than at station A. The third section will also be 5 miles long and the height of high water will be 0.6 foot greater and the time 30 minutes later than at station A. The fourth section will be 2½ miles long and the height of high water 0.9 foot greater and the time 45 minutes later than at station A.

258. The tide reducers for soundings in each of sections 2, 3, and 4 may be derived directly from the curves for station A by reading the curves at points which are as many minutes earlier than the times of the soundings as there are minutes in the time allowance for each section and multiplying the readings by the ratio of ranges. For offshore areas the range of tide may generally be taken the same as at the nearest point along the coast.

TEMPERATURE AND DENSITY OBERVATIONS

259. At some tide stations, temperature and density observations are taken incidentally to the main purpose of securing the tide record. These observations are taken daily at the time the tide station is visited and are recorded in form 457 (fig. 29). The water to be tested must be dipped from just below the surface. The order of procedure in making the observations is indicated in detail on the back of the form. The record is to be forwarded to the office at the close of each calendar month.

TEMPERATURE

260. In general, the temperatures will be given to the nearest tenth or nearest half degree in the centigrade scale. The scale of the centigrade thermometer is usually divided into degrees and half degrees. If a Fahrenheit thermometer is being used, it should be indicated by the letter F at the top of the column containing the temperatures. The record includes the temperature of the outdoor air, the temperature of the sea water immediately after it has been

drawn from the harbor or sea, and the temperature of the water in the jar in which the hydrometer is floated taken at the time of the hydrometer reading. The temperature of the sea water must be taken in the bucket immediately after the water has been drawn and before

Form 457
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
Rev. Dec., 1930

DENSITY AND TEMPERATURE

Lat. 39° 21' N

Station Atlantic City (Steel Pier), N. J. Long. 74° 25' W

Month August Year 1934 Observer Samuel Deitch

	Degrees.	Date.		Density.	Date.
Warmest Sea Water	23.3	Aug. 25th	*Heaviest Sea Water	1.0239	Aug. 11th
Coldest Sea Water	15.6	Aug. 11th	*Lightest Sea Water	1.0222	Aug. 21st

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE			HYDROMETER No.	DENSITY		*SALINITY 0/00	REMARKS
		Outdoor Air	Sea Water	Water in Jar		Observed Reading	*Reduced Value		
	h. m.	°	°	°			15° C.		
1	12 42	26.2	16.8	18.1	13035	1.0 230	1.0 236	31.9	
2	11 44	25.2	21.3	22.0		1.0 227	1.0 232	31.4	
3	16 10	21.7	18.1	19.0		1.0 226	1.0 234	31.6	
4	18 15	26.9	17.4	19.5		1.0 226	1.0 235	31.8	
5	13 23	27.3	18.0	19.3		1.0 226	1.0 235	31.8	
6	12 11	20.2	19.5	19.6		1.0 219	1.0 228	30.8	
7	8 33	20.2	19.4	19.6		1.0 222	1.0 231	31.2	
8	12 02	24.2	21.4	21.9		1.0 217	1.0 232	31.4	
9	11 47	24.7	22.8	23.1		1.0 213	1.0 231	31.2	
10	12 04	22.3	22.5	22.6		1.0 216	1.0 233	31.5	
11	14 00	21.6	15.6	17.5		1.0 234	1.0 239	32.3	
12	13 52	21.8	19.0	19.6		1.0 223	1.0 232	31.4	
13	13 51	21.9	18.9	19.4		1.0 218	1.0 227	30.7	
14	12 22	23.4	21.1	21.7		1.0 213	1.0 227	30.7	
15	12 55	25.9	20.7	21.9		1.0 214	1.0 229	31.0	
16	12 23	22.8	20.9	21.4		1.0 214	1.0 228	30.8	
17	12 30	21.0	21.6	21.6		1.0 209	1.0 223	30.2	
18	16 41	25.3	22.7	23.4		1.0 209	1.0 228	30.8	
19	9 27	21.9	22.4	22.5		1.0 209	1.0 226	30.6	
20	12 13	29.0	22.4	23.3		1.0 210	1.0 229	31.0	
21	12 29	20.7	22.0	21.7		1.0 208	1.0 222	30.0	
22	12 47	22.1	22.2	22.5		1.0 212	1.0 229	31.0	
23	12 25	24.0	22.6	23.0		1.0 209	1.0 227	30.7	
24	12 36	24.0	22.8	23.3		1.0 211	1.0 230	31.1	
25	12 50	27.2	23.3	24.0		1.0 211	1.0 231	31.2	
26	9 50	22.8	22.2	22.5		1.0 215	1.0 232	31.4	
27	11 58	23.8	22.5	22.6		1.0 212	1.0 229	31.0	
28	12 21	20.2	22.4	22.4		1.0 215	1.0 232	31.4	
29	11 48	20.1	21.2	21.0		1.0 216	1.0 229	31.0	
30	12 10	18.6	20.5	20.4		1.0 216	1.0 228	30.8	
31	12 03	20.5	20.4	20.2		1.0 216	1.0 227	30.7	
Sum			644.6				31.7131	964.4	
Mean			20.79				1.0230	31.11	

* Not to be filled out by observer.

11—4513 (OVER) Density reduced by C. I. C. date Nov. 30, 1934.

FIGURE 29.—Form 457, density and temperature.

it has had time to be affected by the temperature of the surrounding air. The temperature of the water in the jar, which is used to reduce the hydrometer reading to a standard temperature, is not taken until there has been time for the water, the jar, and the hydrometer to become adjusted to a uniform temperature. Sometimes the column of mercury in the thermometer may become separated in sections,

causing erroneous readings. When this occurs the broken sections can usually be jarred together by hand. Readings of different thermometers should be occasionally checked by comparison with each other.

261. The table below, which gives equivalent readings in centigrade and Fahrenheit thermometer scales, affords a convenient means for converting the readings from one of these scales to those of the other scale between the limits −20° and 39.5° C. Beyond these limits the following formula may be used: Fahrenheit reading=32°+ (centigrade reading×1.8).

Conversion of centigrade to Fahrenheit scale

° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.
−20.0	−4	−10.0	14	0.0	32	10.0	50	20.0	68	30.0	86
−19.5	−3	−9.5	15	0.5	33	10.5	51	20.5	69	30.5	87
−19.0	−2	−9.0	16	1.0	34	11.0	52	21.0	70	31.0	88
−18.5	−1	−8.5	17	1.5	35	11.5	53	21.5	71	31.5	89
*−18.0	0	*−8.0	18	*2.0	36	*12.0	54	*22.0	72	*32.0	90
−17.5	0	−7.5	18	2.5	36	12.5	54	22.5	72	32.5	90
−17.0	1	−7.0	19	3.0	37	13.0	55	23.0	73	33.0	91
−16.5	2	−6.5	20	3.5	38	13.5	56	23.5	74	33.5	92
−16.0	3	−6.0	21	4.0	39	14.0	57	24.0	75	34.0	93
−15.5	4	−5.5	22	4.5	40	14.5	58	24.5	76	34.5	94
−15.0	5	−5.0	23	5.0	41	15.0	59	25.0	77	35.0	95
−14.5	6	−4.5	24	5.5	42	15.5	60	25.5	78	35.5	96
−14.0	7	−4.0	25	6.0	43	16.0	61	26.0	79	36.0	97
−13.5	8	−3.5	26	6.5	44	16.5	62	26.5	80	36.5	98
−13.0	9	−3.0	27	7.0	45	17.0	63	27.0	81	37.0	99
−12.5	10	−2.5	28	7.5	46	17.5	64	27.5	82	37.5	100
*−12.0	10	*−2.0	28	*8.0	46	*18.0	64	*28.0	82	*38.0	100
−11.5	11	−1.5	29	8.5	47	18.5	65	28.5	83	38.5	101
−11.0	12	−1.0	30	9.0	48	19.0	66	29.0	84	39.0	102
−10.5	13	−0.5	31	9.5	49	19.5	67	29.5	85	39.5	103

* When two values in the column for the centigrade scale are given for the same whole degree in the Fahrenheit scale the one indicated by the asterisk should be taken when converting the Fahrenheit readings into the centigrade scale.

DENSITY

262. The unit of density is the density of fresh water at a temperature of 4° C. The actual density of the water at tide stations may vary from a little less than unity for fresh water at a temperature of more than 4° C. to approximately 1.031 for the heaviest sea water. To provide for this entire range of density three hydrometers are necessary—one with a scale ranging from 0.996 to 1.011, a second with scale from 1.010 to 1.021, and a third with scale from 1.020 to 1.031. The particular hydrometers to be used at any tide station will, of course, depend upon the density of the water, and the observer will select the hydrometers which will float with the stem partly immersed.

263. The hydrometers are numbered for identification and have been tested by the Bureau of Standards. Tables of corrections will be furnished when necessary. The number of the hydrometer used for each observation should be entered in form 457.

264. The method of reading the scale of the hydrometer, which is graduated downward, is illustrated in figure 30. Except for densities less than unity, the first two figures will always be 1.0, as printed in the column of density in form 457. The two figures immediately

following will be determined by the first numbered scale graduation above the surface of the water, and if this is less than 10, it should be prefixed by a zero (0). The last figure, representing the fourth decimal place in the reading, is determined by the smallest subdivisions, each of which represents a change of 0.0002 in density. If the density of the water is less than unity, the printed figures 1.0 in the form should be stricken out and the reading as illustrated in figure 30 substituted.

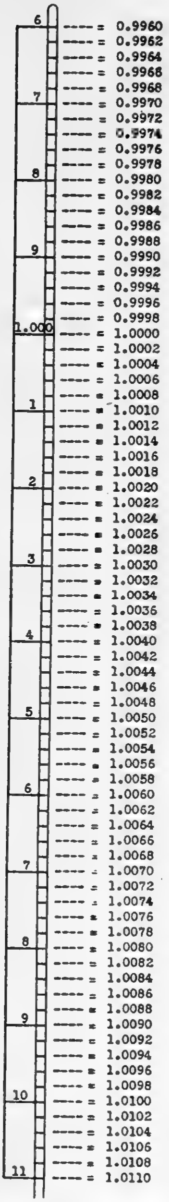

FIGURE 30.—Graduations of hydrometer scale.

265. The water whose density is to be tested is poured into the jar provided for the purpose and the hydrometer floated in the same. A thermometer is then placed in the jar to obtain the temperature for correcting the density reading. A sufficient time should be allowed to elapse to permit the hydrometer, thermometer, and retaining jar to acquire the same temperature as the water. In reading the hydrometer the eye should be brought to the level of the surface of the water and the reading taken which appears to coincide with the level surface. After using, the jar and instruments are to be carefully cleaned to prevent the accumulation of salt.

266. Reduction of density.—The density of sea water as observed depends not only upon the amount of solube matter contained in a unit volume but also upon the temperature of the water at the time of observations. It is, therefore, necessary to reduce the observed densities to some standard temperature in order that they may be comparable and indicate the amount of matter held in solution.

267. The table on pages 86–87 gives a series of differences to be applied to the observed densities in order to reduce them to a standard temperature of 15° C. The table, which is based upon data given in appendix 6 of the United States Coast and Geodetic Survey Report for 1891, is applicable to readings of a hydrometer standardized at a temperature of 15° C. with reference to unit density at 4° C. If the hydrometer used is standardized at some other temperature or refers to another unit density, a further correction will be necessary. The tabular differences include the correction due to the expansion or contraction of the hydrometer itself as well as the change in the density of the water arising from changes in temperature, and should be applied according to sign to the observed hydrometer readings.

268. The differences in the table, which are expressed in ten-thousandths of a unit, are given for each whole degree of temperature from 0° to 35° C., and for each change of 0.0010 in the density from unity to 1.0310. For observed densities less than unity, the top line of the table may be used without material error. The following example illustrates the use of the table: Suppose a hydrometer reading of 1.0244 has been taken when the temperature

of the water in the jar is 11.5° C. The nearest observed density reading given in the table is 1.0240. Following this line, we find differences of −7 and −5 for temperature 11° and 12°, respectively, giving an interpolated difference of −6 for a temperature of 11.5°. This difference of −6 applied to the original hydrometer reading of 1.0244 gives 1.0238 as the reduced value.

269. In the heading of form 457 the heaviest and lightest sea water pertain to the reduced values.

270. Salinity.—The salinity of sea water is defined as the number of grams of salts contained in 1,000 grams of sea water. While the total amount of salts contained in a given volume of sea water varies in different places, the relative portions of the different kinds of salts is nearly constant in all parts of the ocean. For example, sodium chloride or common table salt constitutes nearly 78 percent of all the salts in any locality. Chemical analysis has shown that 1,000 grams of sea water contain in solution an average of 35 grams of salts of various kinds, of which about 27 grams is common table salt.

271. The salinity of sea water may be determined by several different methods, one of the simplest methods being based upon the density of the water as obtained from the use of the hydrometer. The density depends upon the salinity and the temperature of the water. The table on page 88 gives the salinity corresponding to different densities at the standard temperature of 15° C., to which the densities in form 457 are reduced. This table was compiled from table 2 on page 38 of Coast and Geodetic Survey Special Publication No. 61, Physical Laws Underlying the Scale of a Sounding Tube. Through the use of this table the values for the salinity in form 457 may be easily obtained from the reduced densities in the preceding column.

Differences for reducing densities of sea water to 15° C.

Observed density	Temperature of water in jar																			Observed density
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	
	Diff.	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	
1.0000	−3	−4	−5	−5	−6	−6	−6	−6	−6	−5	−5	−4	−3	−2	−1	0	1	3	4	1.0000
1.0010	−4	−5	−6	−6	−6	−6	−6	−6	−6	−5	−5	−4	−3	−2	−1	0	1	3	4	1.0010
1.0020	−4	−5	−6	−6	−7	−7	−6	−6	−6	−6	−5	−4	−3	−2	−1	0	1	3	5	1.0020
1.0030	−5	−6	−6	−7	−7	−7	−7	−6	−6	−6	−5	−4	−3	−2	−1	0	1	3	5	1.0030
1.0040	−5	−6	−7	−7	−7	−7	−7	−7	−6	−6	−5	−4	−3	−2	−1	0	1	3	5	1.0040
1.0050	−6	−7	−7	−7	−8	−7	−7	−7	−7	−6	−5	−5	−4	−3	−1	0	1	3	5	1.0050
1.0060	−6	−7	−8	−8	−8	−8	−8	−7	−7	−6	−6	−5	−4	−3	−1	0	2	3	5	1.0060
1.0070	−7	−7	−8	−8	−8	−8	−8	−7	−7	−6	−6	−5	−4	−3	−1	0	2	3	5	1.0070
1.0080	−7	−8	−8	−8	−9	−8	−8	−8	−7	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0080
1.0090	−8	−8	−9	−9	−9	−9	−8	−8	−7	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0090
1.0100	−8	−9	−9	−9	−9	−9	−9	−8	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0100
1.0110	−9	−9	−10	−10	−10	−9	−9	−8	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0110
1.0120	−9	−10	−10	−10	−10	−10	−9	−9	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0120
1.0130	−10	−10	−10	−10	−10	−10	−9	−9	−8	−7	−6	−5	−4	−3	−2	0	2	3	5	1.0130
1.0140	−10	−11	−11	−11	−11	−10	−10	−9	−8	−7	−7	−6	−4	−3	−2	0	2	3	5	1.0140
1.0150	−11	−11	−11	−11	−11	−10	−10	−9	−9	−8	−7	−6	−4	−3	−2	0	2	3	5	1.0150
1.0160	−11	−11	−12	−11	−11	−11	−10	−10	−9	−8	−7	−6	−4	−3	−2	0	2	4	6	1.0160
1.0170	−12	−12	−12	−12	−12	−11	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0170
1.0180	−12	−12	−12	−12	−12	−11	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0180
1.0190	−13	−13	−13	−13	−12	−12	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0190
1.0200	−13	−13	−13	−13	−13	−12	−11	−11	−10	−9	−7	−6	−5	−3	−2	0	2	4	6	1.0200
1.0210	−14	−14	−14	−13	−13	−12	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	2	4	6	1.0210
1.0220	−14	−14	−14	−14	−13	−13	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	2	4	6	1.0220
1.0230	−15	−15	−14	−14	−14	−13	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	2	4	6	1.0230
1.0240	−15	−15	−15	−14	−14	−13	−12	−12	−10	−9	−8	−7	−5	−3	−2	0	2	4	6	1.0240
1.0250	−16	−15	−15	−15	−14	−13	−13	−12	−11	−9	−8	−7	−5	−4	−2	0	2	4	6	1.0250
1.0260	−16	−16	−16	−15	−15	−14	−13	−12	−11	−10	−8	−7	−5	−4	−2	0	2	4	6	1.0260
1.0270	−17	−16	−16	−15	−15	−14	−13	−12	−11	−10	−8	−7	−5	−4	−2	0	2	4	6	1.0270
1.0280	−17	−17	−16	−16	−15	−14	−13	−12	−11	−10	−9	−7	−5	−4	−2	0	2	4	6	1.0280
1.0290	−18	−17	−17	−16	−16	−15	−14	−13	−12	−10	−9	−7	−5	−4	−2	0	2	4	6	1.0290
1.0300	−18	−18	−17	−17	−16	−15	−14	−13	−12	−10	−9	−7	−6	−4	−2	0	2	4	6	1.0300
1.0310	−19	−18	−18	−17	−16	−15	−14	−13	−12	−10	−9	−7	−6	−4	−2	0	2	4	7	1.0310

***Differences for reducing densities of sea water to 15° C.*—Continued**

Observed density	Temperature of water in jar																		Observed density
	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°	33°	34°	35°	
	Diff.	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	*Diff.*	
1.0000	4	6	8	10	12	14	16	19	21	23	26	29	31	34	37	40	43	46	1.0000
1.0010	4	6	8	10	12	14	16	19	21	23	26	29	32	34	37	40	43	47	1.0010
1.0020	5	7	8	10	12	14	17	19	21	24	26	29	32	35	38	41	44	47	1.0020
1.0030	5	7	8	10	13	15	17	19	22	24	27	30	32	35	38	41	44	47	1.0030
1.0040	5	7	9	11	13	15	17	19	22	24	27	30	33	35	38	41	44	48	1.0040
1.0050	5	7	9	11	13	15	17	20	22	24	27	30	33	36	39	42	45	48	1.0050
1.0060	5	7	9	11	13	15	17	20	22	25	28	30	33	36	39	42	45	49	1.0060
1.0070	5	7	9	11	13	15	18	20	22	25	28	31	33	36	39	43	45	49	1.0070
1.0080	5	7	9	11	13	15	18	20	23	25	28	31	34	37	40	43	46	49	1.0080
1.0090	5	7	9	11	13	16	18	20	23	26	28	31	34	37	40	43	46	50	1.0090
1.0100	5	7	9	11	14	16	18	21	23	26	29	32	34	37	40	44	47	50	1.0100
1.0110	5	7	9	12	14	16	18	21	23	26	29	32	35	38	41	44	47	51	1.0110
1.0120	5	7	9	12	14	16	19	21	24	26	29	32	35	38	41	44	48	51	1.0120
1.0130	5	8	10	12	14	16	19	21	24	27	29	32	35	38	42	45	48	51	1.0130
1.0140	5	8	10	12	14	17	19	22	24	27	30	33	36	39	42	45	48	52	1.0140
1.0150	5	8	10	12	14	17	19	22	24	27	30	33	36	39	42	45	49	52	1.0150
1.0160	6	8	10	12	15	17	19	22	25	27	30	33	36	39	43	46	49	53	1.0160
1.0170	6	8	10	12	15	17	20	22	25	28	31	34	37	40	43	46	49	53	1.0170
1.0180	6	8	10	12	15	17	20	22	25	28	31	34	37	40	43	47	50	53	1.0180
1.0190	6	8	10	13	15	17	20	23	25	28	31	34	37	40	44	47	50	54	1.0190
1.0200	6	8	10	13	15	18	20	23	26	28	31	34	38	41	44	47	51	54	1.0200
1.0210	6	8	10	13	15	18	20	23	26	29	32	35	38	41	44	48	51	55	1.0210
1.0220	6	8	11	13	15	18	21	23	26	29	32	35	38	41	45	48	51	55	1.0220
1.0230	6	8	11	13	16	18	21	24	26	29	32	35	38	42	45	48	52	55	1.0230
1.0240	6	8	11	13	16	18	21	24	27	29	32	36	39	42	45	49	52	56	1.0240
1.0250	6	9	11	13	16	19	21	24	27	30	33	36	39	42	46	49	53	56	1.0250
1.0260	6	9	11	13	16	19	21	24	27	30	33	36	39	43	46	50	53	57	1.0260
1.0270	6	9	11	14	16	19	22	24	27	30	33	37	40	43	46	50	53	57	1.0270
1.0280	6	9	11	14	16	19	22	25	28	30	34	37	40	43	47	50	54	57	1.0280
1.0290	6	9	11	14	16	19	22	25	28	31	34	37	40	44	47	51	54	58	1.0290
1.0300	6	9	11	14	17	19	22	25	28	31	34	37	41	44	47	51	55	58	1.0300
1.0310	7	9	12	14	17	20	22	25	28	31	34	38	41	44	48	51	55	59	1.0310

Corresponding densities and salinities

[Density at 15° C.—Salinity in parts per 1,000]

Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity
0.9991	0.0	1.0046	7.1	1.0101	14.2	1.0156	21.4	1.0211	28.6	1.0266	35.8
.9992	.0	1.0047	7.2	1.0102	14.4	1.0157	21.6	1.0212	28.8	1.0267	35.9
.9993	.1	1.0048	7.3	1.0103	14.5	1.0158	21.7	1.0213	28.9	1.0268	36.0
.9994	.3	1.0049	7.5	1.0104	14.6	1.0159	21.8	1.0214	29.0	1.0269	36.2
.9995	.4	1.0050	7.6	1.0105	14.8	1.0160	22.0	1.0215	29.1	1.0270	36.3
.9996	.5	1.0051	7.7	1.0106	14.9	1.0161	22.1	1.0216	29.3	1.0271	36.4
.9997	.7	1.0052	7.9	1.0107	15.0	1.0162	22.2	1.0217	29.4	1.0272	36.6
.9998	.8	1.0053	8.0	1.0108	15.2	1.0163	22.4	1.0218	29.5	1.0273	36.7
.9999	.9	1.0054	8.1	1.0109	15.3	1.0164	22.5	1.0219	29.7	1.0274	36.8
1.0000	1.1	1.0055	8.2	1.0110	15.4	1.0165	22.6	1.0220	29.8	1.0275	37.0
1.0001	1.2	1.0056	8.4	1.0111	15.6	1.0166	22.7	1.0221	29.9	1.0276	37.1
1.0002	1.3	1.0057	8.5	1.0112	15.7	1.0167	22.9	1.0222	30.0	1.0277	37.2
1.0003	1.4	1.0058	8.6	1.0113	15.8	1.0168	23.0	1.0223	30.2	1.0278	37.3
1.0004	1.6	1.0059	8.8	1.0114	16.0	1.0169	23.1	1.0224	30.3	1.0279	37.5
1.0005	1.7	1.0060	8.9	1.0115	16.1	1.0170	23.3	1.0225	30.4	1.0280	37.6
1.0006	1.8	1.0061	9.0	1.0116	16.2	1.0171	23.4	1.0226	30.6	1.0281	37.7
1.0007	2.0	1.0062	9.2	1.0117	16.3	1.0172	23.5	1.0227	30.7	1.0282	37.9
1.0008	2.1	1.0063	9.3	1.0118	16.5	1.0173	23.7	1.0228	30.8	1.0283	38.0
1.0009	2.2	1.0064	9.4	1.0119	16.6	1.0174	23.8	1.0229	31.0	1.0284	38.1
1.0010	2.4	1.0065	9.6	1.0120	16.7	1.0175	23.9	1.0230	31.1	1.0285	38.2
1.0011	2.5	1.0066	9.7	1.0121	16.9	1.0176	24.0	1.0231	31.2	1.0286	38.4
1.0012	2.6	1.0067	9.8	1.0122	17.0	1.0177	24.2	1.0232	31.4	1.0287	38.5
1.0013	2.8	1.0068	9.9	1.0123	17.1	1.0178	24.3	1.0233	31.5	1.0288	38.6
1.0014	2.9	1.0069	10.1	1.0124	17.3	1.0179	24.4	1.0234	31.6	1.0289	38.8
1.0015	3.0	1.0070	10.2	1.0125	17.4	1.0180	24.6	1.0235	31.8	1.0290	38.9
1.0016	3.2	1.0071	10.3	1.0126	17.5	1.0181	24.7	1.0236	31.9	1.0291	39.0
1.0017	3.3	1.0072	10.5	1.0127	17.6	1.0182	24.8	1.0237	32.0	1.0292	39.2
1.0018	3.4	1.0073	10.6	1.0128	17.8	1.0183	25.0	1.0238	32.1	1.0293	39.3
1.0019	3.5	1.0074	10.7	1.0129	17.9	1.0184	25.1	1.0239	32.3	1.0294	39.4
1.0020	3.7	1.0075	10.8	1.0130	18.0	1.0185	25.2	1.0240	32.4	1.0295	39.6
1.0021	3.8	1.0076	11.0	1.0131	18.2	1.0186	25.4	1.0241	32.5	1.0296	39.7
1.0022	3.9	1.0077	11.1	1.0132	18.3	1.0187	25.5	1.0242	32.7	1.0297	39.8
1.0023	4.1	1.0078	11.2	1.0133	18.4	1.0188	25.6	1.0243	32.8	1.0298	39.9
1.0024	4.2	1.0079	11.4	1.0134	18.6	1.0189	25.8	1.0244	32.9	1.0299	40.1
1.0025	4.3	1.0080	11.5	1.0135	18.7	1.0190	25.9	1.0245	33.0	1.0300	40.2
1.0026	4.5	1.0081	11.6	1.0136	18.8	1.0191	26.0	1.0246	33.2	1.0301	40.3
1.0027	4.6	1.0082	11.8	1.0137	19.0	1.0192	26.1	1.0247	33.3	1.0302	40.4
1.0028	4.7	1.0083	11.9	1.0138	19.1	1.0193	26.3	1.0248	33.4	1.0303	40.6
1.0029	4.8	1.0084	12.0	1.0139	19.2	1.0194	26.4	1.0249	33.6	1.0304	40.7
1.0030	5.0	1.0085	12.2	1.0140	19.4	1.0195	26.5	1.0250	33.7	1.0305	40.8
1.0031	5.1	1.0086	12.3	1.0141	19.5	1.0196	26.7	1.0251	33.8	1.0306	41.0
1.0032	5.2	1.0087	12.4	1.0142	19.6	1.0197	26.8	1.0252	34.0	1.0307	41.1
1.0033	5.4	1.0088	12.6	1.0143	19.7	1.0198	26.9	1.0253	34.1	1.0308	41.2
1.0034	5.5	1.0089	12.7	1.0144	19.9	1.0199	27.1	1.0254	34.2	1.0309	41.4
1.0035	5.6	1.0090	12.8	1.0145	20.0	1.0200	27.2	1.0255	34.4	1.0310	41.5
1.0036	5.8	1.0091	12.9	1.0146	20.1	1.0201	27.3	1.0256	34.5	1.0311	41.6
1.0037	5.9	1.0092	13.1	1.0147	20.3	1.0202	27.4	1.0257	34.6	1.0312	41.8
1.0038	6.0	1.0093	13.2	1.0148	20.4	1.0203	27.6	1.0258	34.7	1.0313	41.9
1.0039	6.2	1.0094	13.3	1.0149	20.5	1.0204	27.7	1.0259	34.9	1.0314	42.0
1.0040	6.3	1.0095	13.5	1.0150	20.6	1.0205	27.8	1.0260	35.0	1.0315	42.1
1.0041	6.4	1.0096	13.6	1.0151	20.8	1.0206	28.0	1.0261	35.1	1.0316	42.3
1.0042	6.6	1.0097	13.7	1.0152	20.9	1.0207	28.1	1.0262	35.3	1.0317	42.4
1.0043	6.7	1.0098	13.9	1.0153	21.0	1.0208	28.2	1.0263	35.4	1.0318	42.5
1.0044	6.8	1.0099	14.0	1.0154	21.2	1.0209	28.4	1.0264	35.5	1.0319	42.7
1.0045	7.0	1.0100	14.1	1.0155	21.3	1.0210	28.5	1.0265	35.6	1.0320	42.8

INDEX

N

O

P

R

S

T

V

W